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USER'S MANUAL FOR PREMINING PLANNING OF EASTERN SURFACE COAL MINING
VOLUME 3: GEOLOGY OF EASTERN COALFIELDS

by

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This volume is one of a series of six reports designed to provide the surface coal mining industry and its regulators with a comprehensive review of the best available methods for extracting this valuable mineral resource while protecting the fragile environment. The specific objective of this report is to summarize the regional coal geology and the related natural resources. The summary includes geomorphology, climate, water resources, and soils and will serve as a background for many of the hydrologic engineering and land use considerations in the other reports. A study of coal geology and the related natural resources is essential to foster further understanding of the surface mining of coal, the restoration of the mine area, and the environmental impact of mines.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This volume is the third in a series of six reports designed to provide the surface coal mining industry and its regulators with a comprehensive review of the best available methods for extracting this valuable mineral resource while protecting the fragile environment. The specific objective of this report is to summarize the regional coal geology and the related natural resources. The summary includes geomorphology, climate, water resources, and soils and will serve as a background for many of the hydrologic engineering and land use considerations in the other reports. A study of coal geology and the related natural resources is essential to foster further understanding of the surface mining of coal, the restoration of the mine area, and the environmental impact of mines.

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ABSTRACT

The purpose of this research effort was to study the surface mining of coal in the Eastern United States and to establish guidelines for the development, evaluation, and selection of mining and reclamation plans before actual mining begins. This study was designed to consider the geological and hydrological settings before mining as the basic information for premining planning, and to develop guidelines for assessing alternatives in surface mine engineering, water management, and land use planning. The implementation of these guidelines should cause surface mining to be less detrimental to the environment.

The recommended methods, techniques and alternatives for selecting and designing mining systems, based on a review and critical evaluation of the methods reported in the literature and applied in the field, are presented in a series of six reports. These reports comprise a User's Manual for the Premining Planning of Surface Coal Mining Operations in the Eastern United States.

In this report, Volume 3, the geology and the related natural resources of the eastern coalfields are addressed. The primary purpose of the report is to provide a summary of the regional coal geology, climate, water resources, and soils. This summary will serve as a background for many of the hydrologic, engineering, and land use considerations in the other reports.

This report was submitted in fulfillment of Grant No. R803883 by the Departments of Mineral Engineering and Geosciences of The Pennsylvania State University, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 1, 1975, to May 30, 1978, and work was completed as of December, 1981.

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ABBREVIATIONS

AGFC	Arkansas Game and Fish Commission
BSFW	Bureau of Sports Fisheries and Wildlife
COE	Corps of Engineers
FWS	Fish and Wildlife Service
ISWS	Illinois State Water Survey
KWRB	Kansas Water Resources Board
MBIC	Missouri Basin Interagency Committee
MDC	Missouri Department of Conservation
MDEQ	Missouri Division of Environmental Quality
NRPB	National Resources Planning Board
ORBCC	Ohio River Basin Coordinating Committee
OWRB	Oklahoma Water Resources Board
SCS	Soil Conservation Service
UMRBCC	Upper Mississippi River Basin Coordinating Committee
USDA	United States Department of Agriculture
USGS	United States Geological Survey

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The materials contained in this report were prepared as a joint effort by the Department of Mineral Engineering and the Department of Geosciences of the College of Earth and Mineral Sciences of The Pennsylvania State University. Dr. R. V. Ramani, of the Department of Mineral Engineering, provided overall management for the project. The materials contained in this report were prepared under the guidance and direction of Dr. R. R. Parizek of the Department of Geosciences. He was assisted by Mr. J. Sgambat also of the Geosciences Department and Mr. M. L. Clar of the Department of Mineral Engineering. Mr. Clar also served as project coordinator for the research effort.

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SECTION 1

INTRODUCTION

SCOPE AND OBJECTIVES

This report is the third of a series of six reports. These reports are designed to provide the coal mining industry and its regulators with a comprehensive review of the best available methods for integrating the extraction of that mineral resource with the protection and conservation of the associated natural resources. The specific objective in this report is to provide a summary review of the existing physical setting for three eastern provinces: the Eastern Coal Province (also referred to as the Appalachian Region), the Eastern Interior Coal Province and the Western Interior Coal Province. The discussion of the existing physical setting focuses primarily on their coal geology. Supporting discussions of the related natural resources are also provided. The discussion includes geomorphology, climate, water resources, and soils.

CONTENTS

The contents of this report have been structured into seven sections. In each section, a separate resource or area of discussion is addressed. Section 1 contains the introduction. The summary and conclusions are presented in Section 2.

Section 3 begins the discussion of the physical environment of the eastern coal provinces with a description of their structural and geomorphic setting. This section is composed of three major discussion areas. First, there is a review of structural features; the features discussed include: folds, faults, erosional channels, slump blocks, ice-shove structures, variable depositional slope and compaction, joints and zones of fracture concentration. Second, there is a review of the principal geomorphic components; these components consist of both topographic elements (elevation, relief, slope, and exposure) and drainage elements (the form and texture of drainageways, drainage areas, and drainage patterns). Third, a region-by-region summary of the major physiographic divisions in the study area is provided.

Section 4 contains the information on the coal geology of the eastern coal provinces. In this discussion, a brief review of numerous important topics that are associated with the coal geology is presented; these topics include the occurrence of sulfur in coal and the paleoenvironments of coal deposits. Most of the discussion consists of a region-by-region summary of the coal geology. The discussion is directed to four major elements of coal geology:

1. The sulfur content of the coals,
2. The location of the mining districts,
3. The existing sedimentation models of the given region, and
4. The occurrence of limestone deposits.

In Section 5, there is a region-by-region summary of the climate of the eastern coal provinces. This discussion is about the five dominant climatic elements: temperature, humidity, precipitation, solar radiation, and wind.

The water resources of the eastern coal provinces are summarized in Section 6. The summary, on a region-by-region basis, is subdivided into separate discussions of surface water and groundwater. Data are provided on the major rivers in each region and on their flow and quality. Also identified are the major producing aquifers of the regions and their yields, quality, and use.

In Section 7, generalized soils information on a region-by-region basis is provided; the information is based upon those soil characteristics that environmentalists consider important in assessing mining impacts. Soil characteristics include the general physical and chemical properties of the surface and subsoils, soil erodibility, and the overall rating of the soils with respect to their soil capability classes.

SECTION 2

SUMMARY AND CONCLUSIONS

Published geological and related natural resource maps and reports will rarely present the data required for premining planning studies. In some regions, maps and reports will be more complete than they will be in other regions, but in nearly all cases, more detailed site investigation becomes necessary during the advanced stages of mine planning. Prior review of existing geological and hydrological data should be encouraged before more costly site studies are conducted.

Some reports present detailed maps showing the soils with their capabilities and limitations for various land uses. Maps also show the geology of surficial deposits, including thickness, distribution, and character of overburden sediments (especially glacial drift) and the bedrock topography of glaciated regions, with geology of the bedrock surface. Reports also include stratigraphic sequences with isopachous maps of selected stratigraphic units, and structure contour maps on various horizons (often principal coal beds, aquifers, or marker beds).

Maps can also show the locations of various boreholes and water wells, which may have geophysical logs, drill cutting logs, or core logs. Geological correlations between boreholes and outcrops may show regional variations in thickness and lithology. In some cases, these may be plotted with sea level as a datum and include profiles displaying surface and bedrock surface topography, structure, and thickness of principal stratigraphic units, including overburden sediments.

Students and faculty members at various colleges and universities that are often distant from coal-producing regions are investigating paleoenvironments of sedimentation associated with coal. These research efforts may be cited only in thesis abstracts, and if the research is not published in journals, State or federal reports, the abstracts should be on file with departmental or college libraries. Microfilm or Xerox copies of the abstracts are available; they can also be obtained through interlibrary loan or they can be examined in the libraries. In addition, all Ph.D. dissertation abstracts are available on microfilm in Ann Arbor, Michigan.

Investigations may center on data obtained from a single mine where coal has already been completely removed (within 7-½ minute quadrangles, county or multi-county regions), or investigations may cover an entire state or coal basin. They may cover all units within a given cyclothem, or within a single bed of coal, underclay or limestone. Investigative studies are especially helpful in showing the local or regional trends in depositional environments;

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they can also show lithofacies maps, and the control of topographies and structure on coal thickness and quality. They provide information about sulfur distribution and other data that may be helpful in determining coal quality, such as the potential for acid mine drainage (in general terms) and the presence of calcareous shales or limestone beds (which may be available to neutralize acid reactions).

State and federal geological surveys conduct similar studies, which are available as journal publications, reports in state or federal publication series, open file reports, or studies in progress. Geological maps, stratigraphic and structural studies, coal, clay, and limestone resource data are typically included; all maps, studies, and data cover quadrangles or counties. A reader can locate these studies and maps by examining the publication lists of state and federal geological surveys, which will be supplied upon request.

Agencies and organizations similar to those mentioned above such as county and regional planning groups may prepare reports. These sources can also provide other useful geological data concerning publications about mineral and groundwater resources.

Drilling records that are filed with state and federal agencies should also be consulted. These records may be extensive. The Illinois State Geological Survey, for example, has catalogued such findings as the records of more than 500,000 water wells, the borings of coal and structure test holes for foundations, and the logs of borings that were obtained from other programs for subsurface exploration. Pertinent records may be drillers' logs, logs prepared by trained geologists, or borehole geophysical logs. Some States maintain samples (that are available for examination upon request) of drill cuttings or cores from key wells. The Illinois State Geological Survey also has a computer mapping system that allows for the updating of isopachs and structural data on a county-wide basis.

Some States have devised computer storage systems. The Pennsylvania Geological Survey, for example, will provide printout sheets (by township and county) of all the water well data that they have in storage. Frequently, these sheets include data about more recently drilled water wells, as well as data concerning wells drilled for public use, schools, churches, municipalities, and parks.

More detailed site exploration work will be required but that work should only be undertaken after a review of existing geological data and reports. Ideally, an exploration program should be coordinated so that it will provide geological, hydrogeological, and geochemical data, not just data on the number and thickness of coal beds, their depth, elevation, and structural configuration, quality, and overburden thickness. In this way, the total cost of exploration can be kept to a minimum.

SECTION 3

STRUCTURAL AND GEOMORPHIC SETTING FOR THE EASTERN COAL PROVINCES

OVERVIEW

North America has been divided into major physiographic provinces and subprovinces. The characters of the land surface, soils, geological, climatological and vegetational setting of each province and subprovince frequently have much in common. Eastern coalfields fall within some of these major provinces which are briefly described here. Subprovinces, termed sections, can include more valuable detail in mine planning. Mines within a given section are likely to be similar to one another and will frequently encounter soil, rock, drainage and topographic conditions where they have more in common than they have when compared with coal mines located in adjacent sections or in different physiographic provinces.

Classifying land into provinces and subprovinces has some value when subdividing mining districts within state or multi-state regions. Such classification places more emphasis on the topographic details and broad, geological units that significantly influence the geochemical setting of mine sites. Thus, the detailed character (such as the presence or absence of acid-producing strata, calcareous deposits and so forth) of the rocks that are present is not shown. A useful classification scheme was prepared, for example, for the Philipsburg basin of Pennsylvania (Battaglia, Jones and Parizek, 1980; Bachman, 1980) that includes still more detailed data useful in mine planning.

Ultimately it should be possible to classify mining regions in various ways not just by broad relationships. The classification of mining regions could then use a host of valuable data that reveal a combination of factors that are important in mine planning studies.

Such a new classification system might include: number, thickness, and distribution of coal beds; sulfur content of coal; pyrite character and abundance within coal and associated strata (hence their acid producing potential); geochemical character of soil, rock, and groundwater; overburden type, thickness, and character; soils; details of topography; drainage; vegetation; wildlife habitat; land uses and land use potentials; presence of aquifers; distribution of other valuable minerals; and details on groundwater flow systems.

Overlay maps that would display and interpret these types of basic data could be constructed by computer; they could then be modified for scale to meet local planning requirements, modified to include more recent data, or to include new maps as the inventory base is updated. Such an inventory of basic data would find many uses in a society where the competition for space and resources is ever increasing.

STRUCTURAL SETTING

Folds

Coal-producing regions described in this report tend to be located within structural or sedimentary basins that were being filled with continental clastic sediments deposited at or very near sea level. Some of the basins were present and controlled sedimentation for other sedimentary systems in addition to Pennsylvanian-aged rocks (i.e., Mississippian, Silurian, and Ordovician), which predate principal coal deposition during Pennsylvanian time. The sedimentary basins were formed by tectonic forces that operated on a regional scale often involving large sections of the present continent.

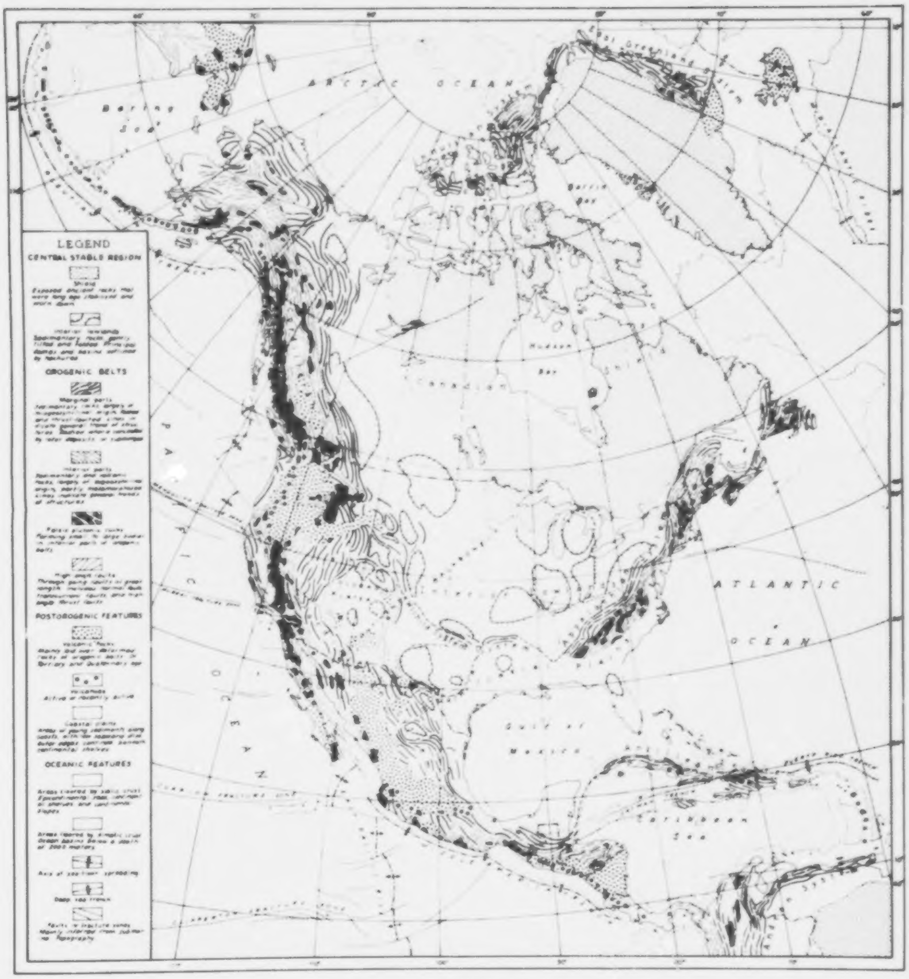
When the reader compares the tectonic map of the U.S. (Figure 1) with the map of coal-producing regions (Figure 2), the two show a close association because the structural depressions that favored coal accumulation also helped to protect these important deposits against subsequent erosion. In Permian and later geological time, some basins continued to receive sediments which buried coal deposits until more recent uplift and erosion. Uplifts along the margins were often greater than uplifts for the deeper sections of these basins, and coal-bearing sediments were completely eroded away. Elsewhere, these basin margins were elevated above sea level from time to time and coal-bearing deposits, which were thinned by erosion between episodes of deposition, were thinner to start with or never appeared at all.

The structural attitude of coal beds within these basins tends to be rather gentle, with bedrock dips that are commonly from one to a few degrees. Broad anticlinal arches, local synclines, local domes and basins are not uncommon within particular coalfields. These minor structures tend to account for detailed variations in coal occurrence, thickness, and quality, together with variations in associated sediments, and often abrupt changes in dip.

Faults

Locally in some districts, beds may be tightly folded and faulted, as in the Broad Top Field of Pennsylvania, where bedrock may dip from 30 to 60 or more degrees. Normal faults, high angle reverse faults, and tear faults are present locally in some basins. These faults tend to be more abundant adjacent to regions that were subjected to mountain building, such as those regions along the western edge of the Appalachians.

Normal and reverse faults can account for the abrupt terminations and dislocations of coal beds in some mining districts. However, these faults tend to be less common in sedimentary basins that are more remote from mountain uplifts, such as the basins in Illinois, Michigan, and the Arkoma (Oklahoma) and Forest City (Iowa, Kansas, Missouri) basins of the Western Interior coal region. Fault structures are less common along broad shelf areas, such as those in the Cherokee Platform (Kansas) and Missouri Platform.


ARCTIC OCEAN
Bering Sea
Baffin Bay
Hudson Bay
ATLANTIC OCEAN
Gulf of Mexico
Caribbean Sea
LEGEND
CENTRAL STABLE REGION
OROGENIC BELTS
POSTOROGENIC FEATURES
OCEANIC FEATURES

(From Philip B. King, The Evolution of North America, Revised Edition (copyright (c) 1959, 1977 by Princeton University Press), Plate I, Tectonic Map of North America. Reprinted by permission of Princeton University Press.

Figure 1. Tectonic map of the United States showing the main structural basins of the Eastern Province.

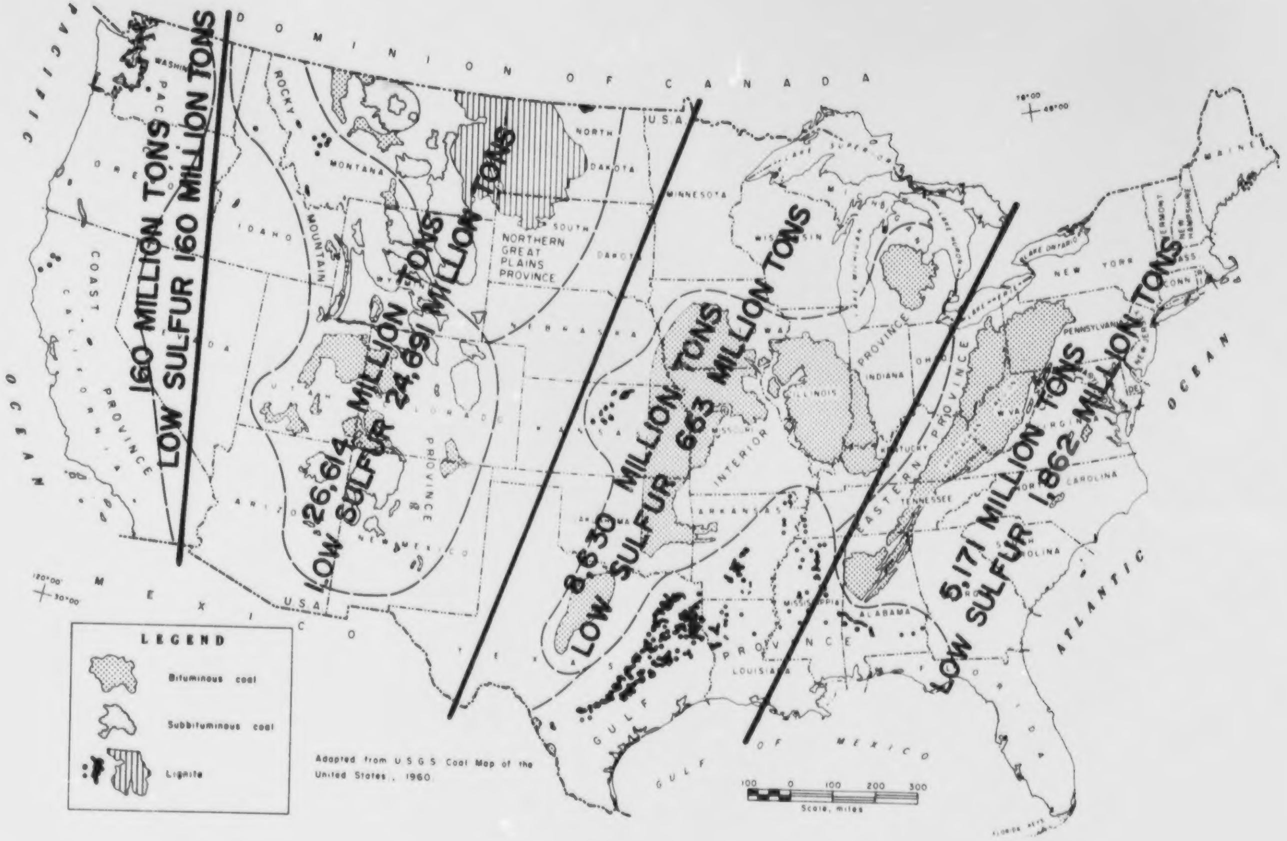

160 MILLION TONS
LOW SULFUR 160 MILLION TONS
26,614 MILLION TONS
LOW SULFUR 24,691 MILLION TONS
8,630 MILLION TONS
LOW SULFUR 663 MILLION TONS
5,171 MILLION TONS
LOW SULFUR 1,862 MILLION TONS
DOMINION OF CANADA
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
NORTHERN GREAT PLAINS PROVINCE
ROCKY MOUNTAIN PROVINCE
INTERIOR PROVINCE
EASTERN PROVINCE
GULF PROVINCE
PACIFIC COAST PROVINCE
LEGEND
Bituminous coal
Subbituminous coal
Lignite
Adapted from U.S.G.S. Coal Map of the United States, 1960
Scale, miles
100 0 100 200 300

Figure 2. Coal-producing regions of the United States.

Lateral or horizontal displacements along tear faults tend to be more common when they are adjacent to mountain uplifts that involve both extensive folding and thrust faulting of sedimentary rock such as uplifts in the Appalachian Mountain belt. These displacements tend to die out away from mountain uplifts. Although displacements may be largely horizontal along tear faults, vertical displacements of 1.5 to 9 m (5 to 30 ft) or more are possible.

Fault identification and location can be important in mine planning, both during the coal exploration and reserve calculation phases of the project as well as in laying out the mine. Where outcrops and nearby active mines are scarce, faults can best be defined from test drilling data. However, stratigraphic data obtained from widely spaced boreholes may be incorrectly interpreted as a sequence of beds with a gentle regional dip rather than as local fault offsets. This error in structural interpretation is often not realized until mining begins and the coal seam terminates abruptly.

Erosional Channels

The industry has applied the term "fault" to any pinchout or termination of coal. "Faults" may or may not be due to a physical offset of rocks caused by differential movement on either side of a fault plane. Hence, coal beds cut by ancient stream channels that were eroded through and below the coal bed and later filled with sediment have been termed "faults," largely because an abrupt termination in the coal seam was noted (Figure 3). These channels commonly, but not exclusively, tend to be filled with sandstones and conglomerates. Similar stream channels were also formed during preglacial and interglacial times. These channels may be filled by glacial drift (outwash sand and gravel, lake deposits, till, and so forth) or be partly or completely buried by drift in glaciated areas. Other possibilities are that these channels may contain partial fills of outwash sand and gravel; they may also contain more recent stream alluvium that is beyond the margin of areas overridden by continental glaciers.

Slump Blocks

The erosion of stream channels in recently deposited sediments also promoted slope failures located symmetrically about the channel. Large rotational slump blocks that further truncated strata along the valley walls (Figure 4) have been recognized in Pennsylvanian-aged strata. Williams and others (1965) have shown the importance of these slump blocks as further proof of the presence of erosional unconformities and disconformities in coal-bearing strata. Irregular attitudes in bedding planes observed in these channel fill sediments were often incorrectly interpreted as depositional cross bedding when, in fact, these attitudes were caused by one or more rotated slump blocks.

Ice-Shove Structures

Deformation by tectonic forces is not the only reason strata may develop dips. Shallow thrust faults, drag folds, and ice shove structural features have been reported in some areas that were overridden by continental ice

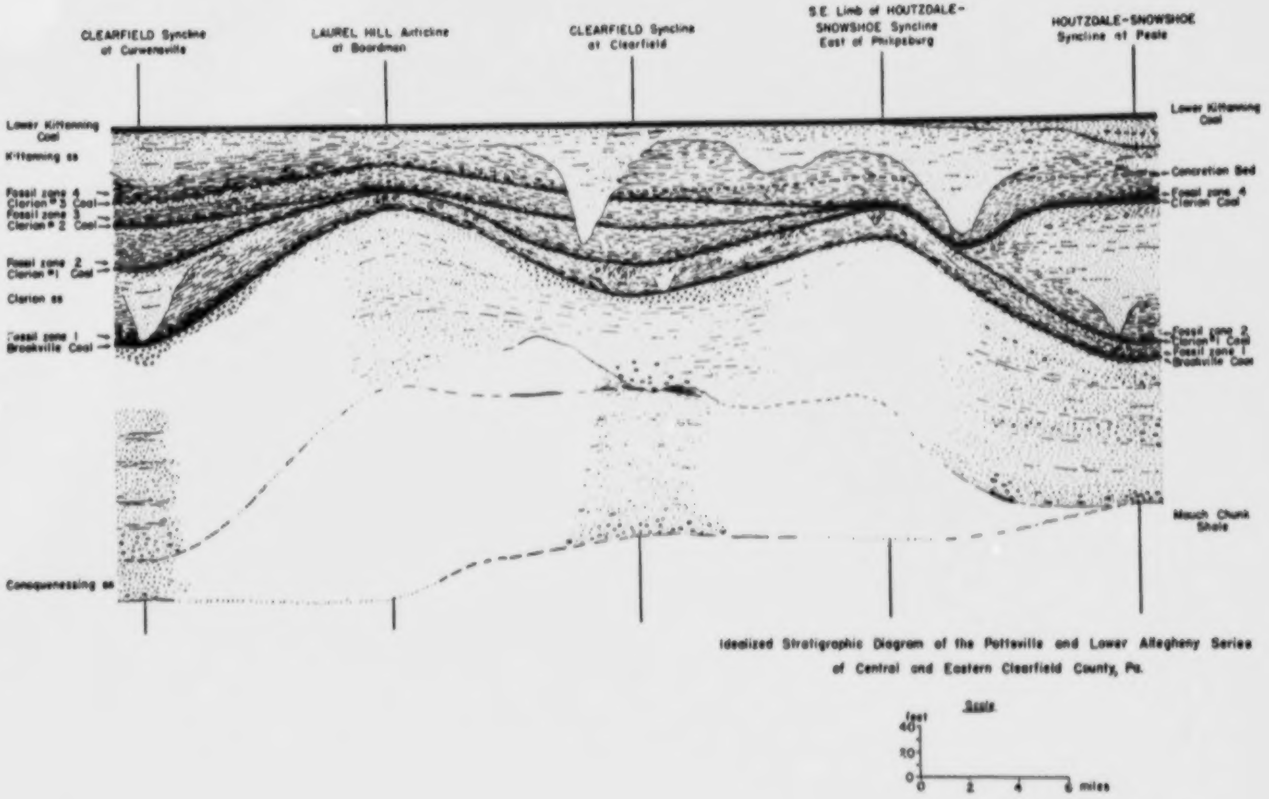

CLEARFIELD Syncline at Curwensville
LAUREL HILL Anticline at Boardman
CLEARFIELD Syncline at Clearfield
S.E. Limb of HOUTZDALE-SNOWSHOE Syncline East of Philipsburg
HOUTZDALE-SNOWSHOE Syncline at Peale
Lower Kittanning Coal
Kittanning ss
Fossil zone 4
Clarion #3 Coal
Fossil zone 3
Clarion # 2 Coal
Fossil zone 2
Clarion #1 Coal
Clarion ss
Fossil zone 1
Brookville Coal
Connoquenessing ss
Lower Kittanning Coal
Concretion Bed
Fossil zone 4
Clarion Coal
Fossil zone 2
Clarion #1 Coal
Fossil zone 1
Brookville Coal
Mauch Chunk Shale
Idealized Stratigraphic Diagram of the Pottsville and Lower Allegheny Series of Central and Eastern Clearfield County, Pa.
Scale
feet
40
20
0
0
2
4
6 miles

Figure 3. Typical channel eroded through coal and filled with channel sandstone. The abrupt termination of coal along the erosional uncomformity and channel fill is often referred to as a "fault" by the coal industry.

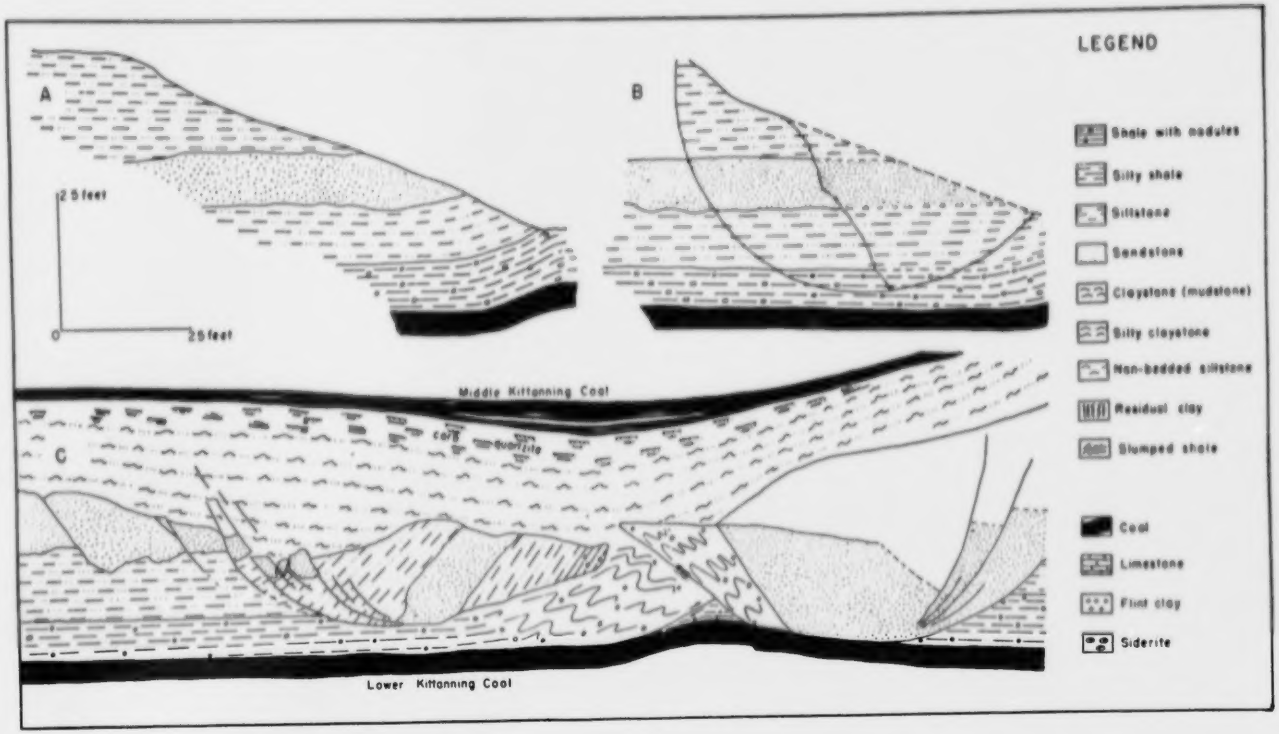

A
B
C
25 feet
0
25 feet
Middle Kittanning Coal
core
quartzite
Lower Kittanning Coal
LEGEND
Shale with nodules
Silty shale
Siltstone
Sandstone
Claystone (mudstone)
Silty claystone
Non-bedded siltstone
Residual clay
Slumped shale
Coal
Limestone
Flint clay
Siderite

Figure 4a. Slump blocks formed on either side of a Pennsylvanian-aged stream channel (E. G. Williams, A. Guber and A. Johnson, 1965). In (a), a sequence of shale, siltstone, and sandstone is eroded along a stream valley. In (b), a slope failure plane starts to form and by (c) the rotational slump blocks are buried by younger sediments.

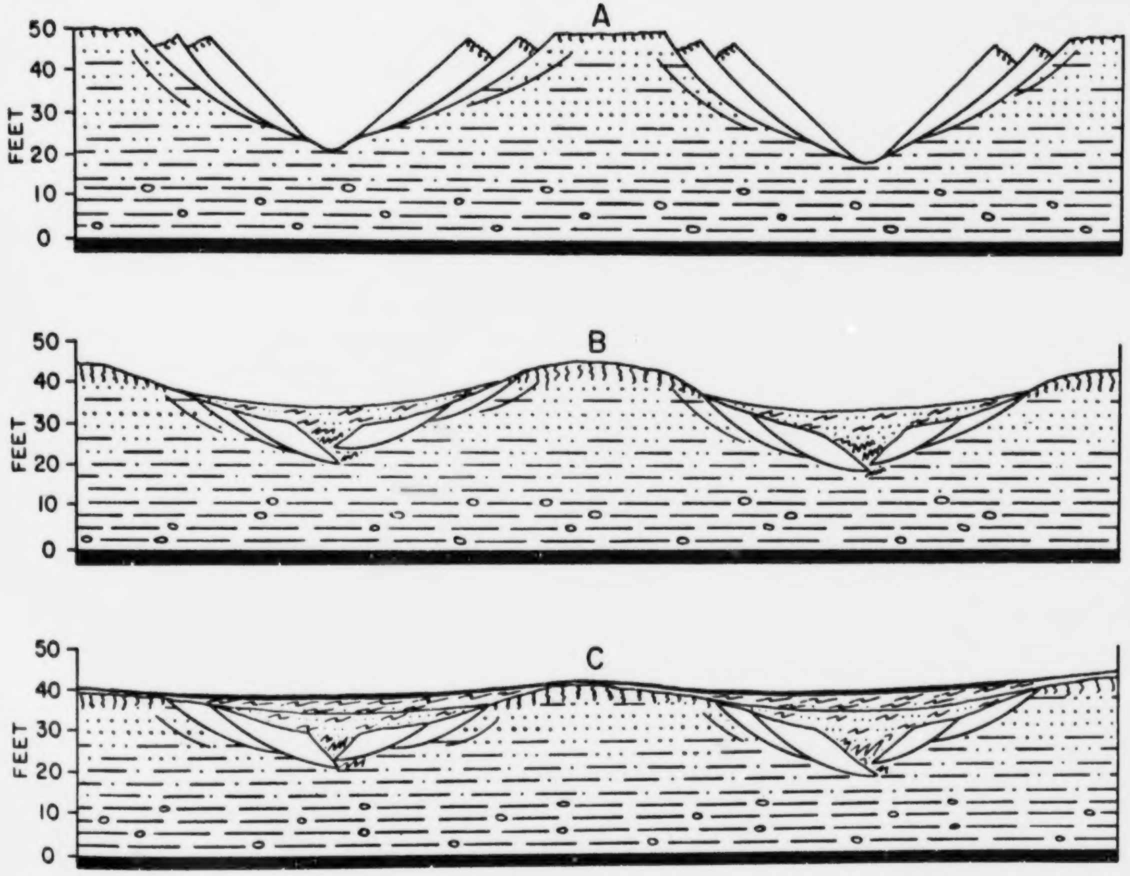


Figure 4b. Sequence of events following the development of slump blocks on either side of a stream valley and the development of a younger coal bed (E. G. Williams, A. Guber and A. Johnson, 1965).

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sheets. These structures tend to be shallow and contain limited structural closure, however, Parizek has mapped ice-shove structures (developed in Silurian and Ordovician-aged dolomitic bedrock of Northern Illinois) that show thrust faults, and massive blocks of bedrock that were dislocated hundreds of feet from their source (Figure 5). Less competent beds of Tertiary and Cretaceous-aged bedrock, composed of substances such as siltstone, shale, lignite, and mudstone, have been folded and thrust faulted by continental glaciers in the High Plains region (Figure 6) and these beds may display 30 to 150 or more meters (100 to 500 or more feet) of structural closures, some with significant topographic relief (Parizek, 1961; 1964). Ice-shove structures tend to be more common and better developed in less competent rocks but are by no means restricted to these strata.

Variable Depositional Slope and Compaction

Dip variations in coal may also be caused by topographic irregularities that were originally present in the coal basin upon which the coal-producing vegetation was growing. These topographic differences commonly influence many aspects of coal strata, such as the thickness and character of coal and associated strata, the presence of splits and riders, and the detailed variations in pyrite distribution.

Differential compaction of the freshly deposited sediments of variable thickness also contributes to elevation differences that are observed within coal-bearing rocks. This compaction also influenced subsequent environments of deposition for overlying strata where slight changes in elevation were caused within seafloors, swamps, and uplands.

Joints

Coal beds within the Eastern Coal Provinces all show good cleat or joint development, which formed as or after the organic matter was transformed from peat to bituminous coal. Cleat orientation is distinct and joints are rather closely spaced and systematic in their orientation. These secondary structures may localize secondary pyrite that is deposited along joint surfaces, and the structures add significantly to the permeability and porosity of coal. It is not uncommon for coal to serve as the principal water-yielding deposit in some sections of mining districts largely because of these well developed secondary openings. Secondary openings encourage the migration of methane gas and the leakage of mine drainage through coal barriers and within coal beds.

In the Eastern Coal Provinces joint development is ubiquitous in all bed rock associated with coal. The spacing, orientation, and degree of development vary widely between individual beds of varying lithology and from mining district to mining district. More massive, well cemented sandstones tend to have more widely spaced joints that cut through the entire sandstone unit whereas some shales and siltstones show tighter, more closely spaced joints. Steep dips to near vertical dips are common for these joints.

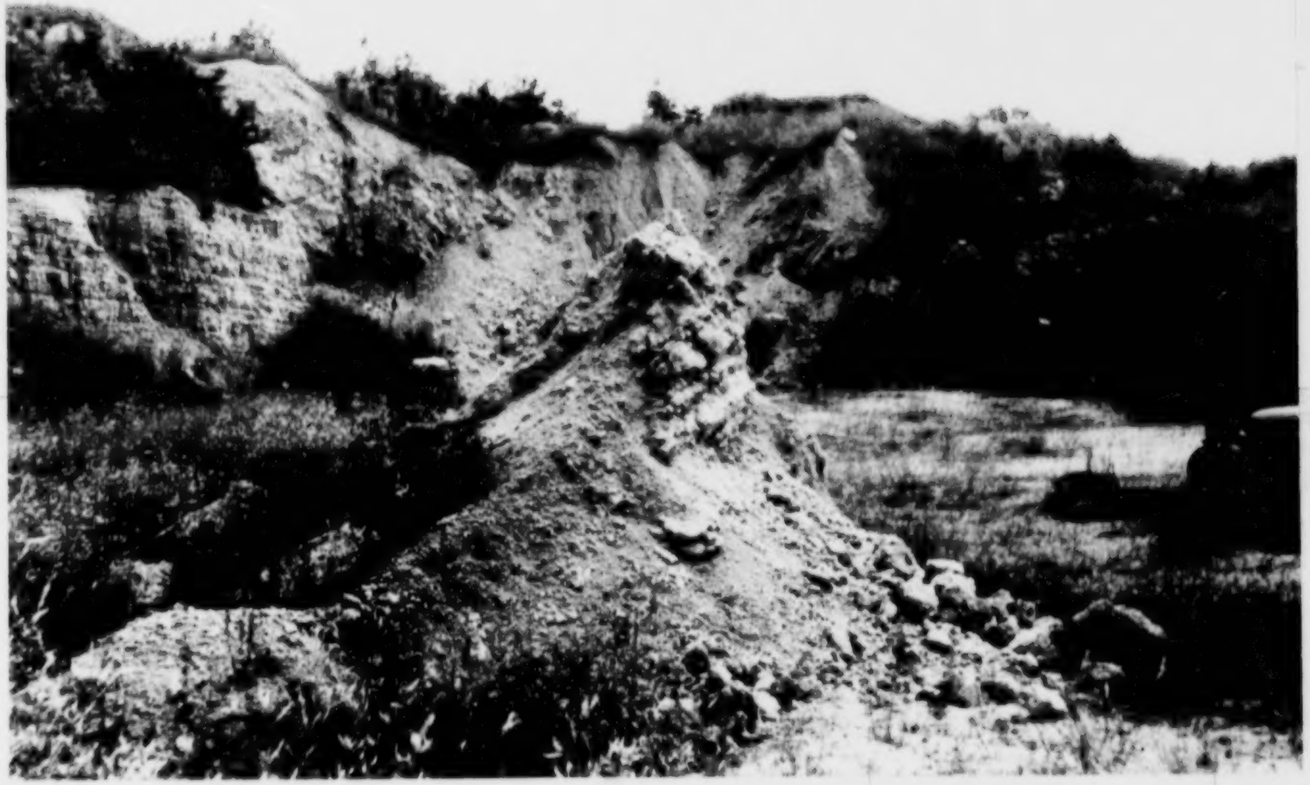

Figure 5. Ice-thrust structures developed in Ordovician dolomite, Ogle County, Illinois. Variable bedrock dips are shown and glacial till underlies various bedrock units that have been thrust on top younger shale beds.

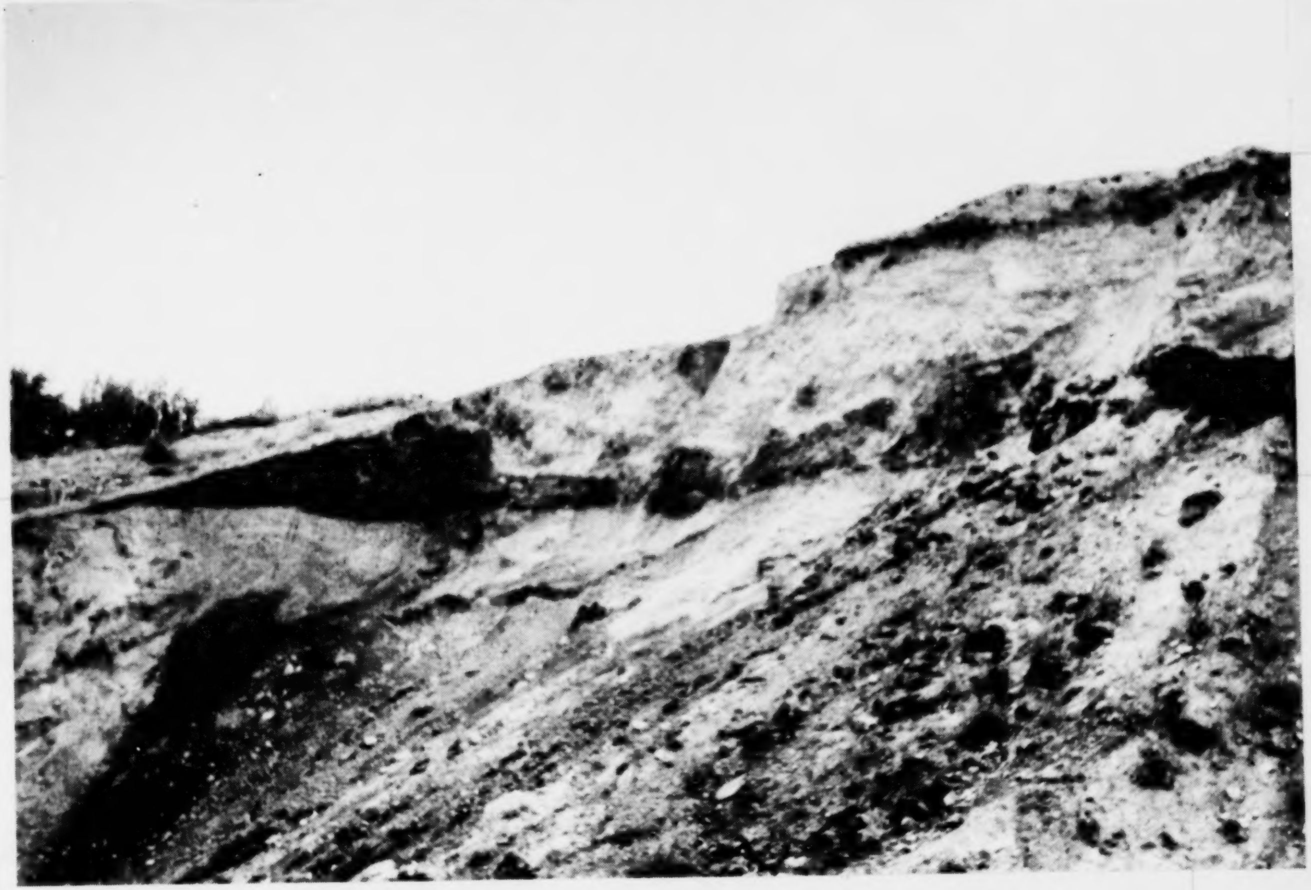

Figure 6. Cretaceous siltstone and shale bedrock thrust over glacial outwash sand and gravel, Alberta, Canada. The dark layer midway up the outcrop is shale.

Joints tend to show systematic orientations within a given region. However, depending upon local tectonic details (Figure 7), slight changes in orientation may occur from site to site within a given region.

These joints add significantly to the permeability characteristics of all strata associated with coal. The abundance and degree of joint development along two or three preferential directions can impart an anisotropic character to the permeability of local aquifers and confining beds. Their steep to near vertical dip and tendency to cut one or more beds of rock add significantly to the vertical permeability of both aquifers and confining beds. These aquifers and confining beds would otherwise tend to display a permeability preference that is parallel to bedding planes.

Joint development within fire or under clays also tends to be widespread for the more firmly compacted and cemented clays. Curvy, polished surfaces show that some minor movement probably occurred along these minor joints to give them slickensides. These minor breaks in otherwise poorly permeable sediments add to their vertical permeability; during mine planning projects, fire clays should not be regarded as impermeable or as aquicludes.

Zones of Fracture Concentration

Zones of fracture concentration are revealed by fracture traces shown on stereo-paired aerial photographs. Fracture zones influence topography, drainage, stream alignments, soil tonal and vegetational alignments, and spring and seepage lines (Lattman and Parizek, 1964; Brown and Parizek, 1971; Parizek, 1971; Siddiqui and Parizek, 1971; Parizek, 1975, 1976) (Figure 8).

Zones of fracture concentration may be 305 m (1000 ft) or more in length but generally are less than 1.6 km (1 mile) in length. Linear features in excess of 1.6 km (1 mile) which are controlled by joints and fractures that are less well understood are termed "linears" or "lineaments". Lineaments are best seen in ERTS satellite images on a 1:250,000 or larger scale, on SKYLAB and U-2 underflight images and photographs (Gold and others, 1974; Parizek, 1975) (Figure 9).

Fracture traces are underlain by nearly vertical zones of fracture concentration; these zones may be 1.5 to 15 m (5 to 50 ft) or more wide, and may contain 5 to 10 closely spaced joints, or the zones may be underlain by hundreds of joints and fractures that give the rock a shattered appearance (Figure 10). Joints may cut all rock units equally well or be concentrated within selected beds in any given sequence of rocks (Parizek, 1971).

These secondary structures are developed within bedrock throughout the eastern mining district, and although they are expressed through overlying transported and residual soils, the structures do not significantly influence the permeability of the unconsolidated overburden deposits. Fracture traces that reveal zones of fracture concentration tend to be obscured by thick overburden deposits, such as glacial drift. Overburden deposits are less important when mapping lineaments.

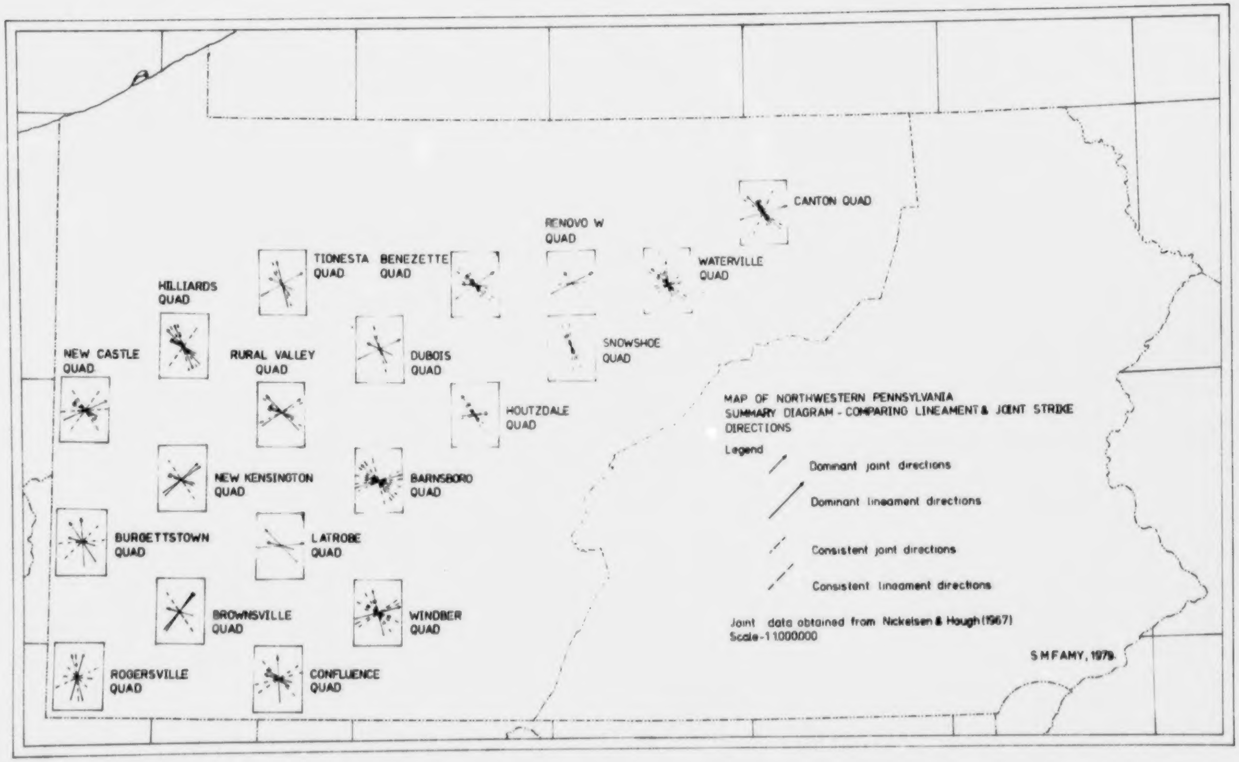
CANTON QUAD
RENOVO W QUAD
WATERVILLE QUAD
TIONESTA QUAD
BENEZETTE QUAD
HILLIARDS QUAD
SNOWSHOE QUAD
NEW CASTLE QUAD
RURAL VALLEY QUAD
DUBOIS QUAD
HOUTZDALE QUAD
NEW KENSINGTON QUAD
BARNSBORO QUAD
BURGETTSTOWN QUAD
LATROBE QUAD
BROWNSVILLE QUAD
WINDBER QUAD
ROGERSVILLE QUAD
CONFLUENCE QUAD
MAP OF NORTHWESTERN PENNSYLVANIA
SUMMARY DIAGRAM - COMPARING LINEAMENT & JOINT STRIKE DIRECTIONS
Legend
Dominant joint directions
Dominant lineament directions
Consistent joint directions
Consistent lineament directions
Joint data obtained from Nickelsen & Hough (1967)
Scale-1:1000000
S M FAMY, 1979

Figure 7. Orientation of joints within western Pennsylvania showing changes with tectonic setting (W. Kowalik and D. Gold, 1975).

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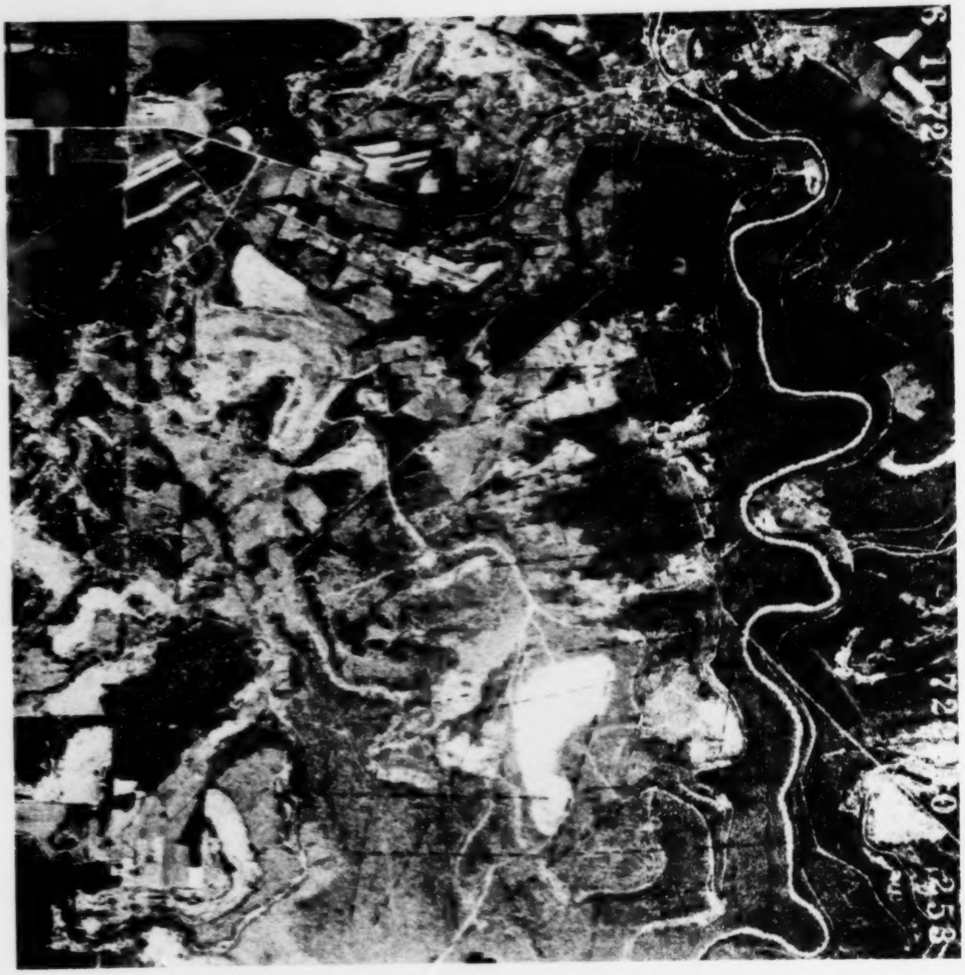

Figure 8. Fracture traces shown in a strip mine region near Medera, Pennsylvania. Dashed lines show selected fracture traces.

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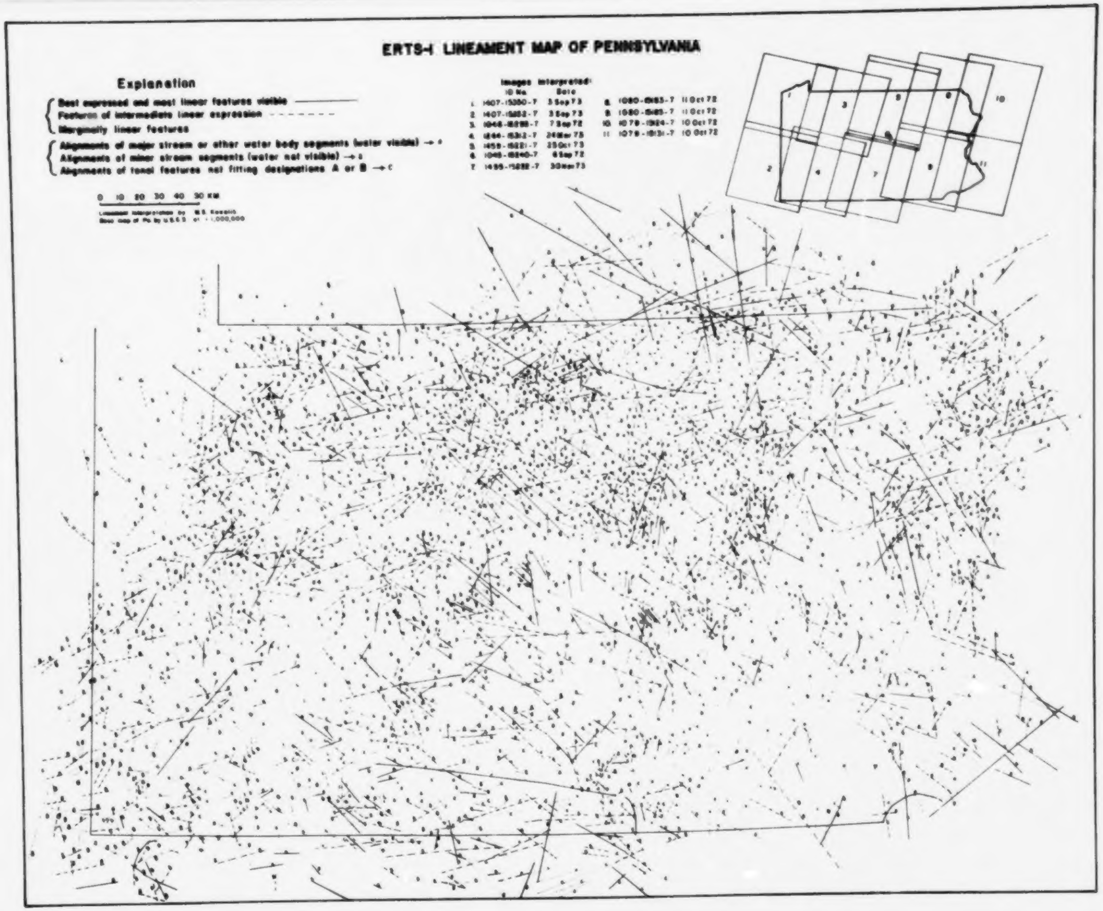
ERTS-1 LINEAMENT MAP OF PENNSYLVANIA
Explanation
Best expressed and most linear features visible
Features of intermediate linear expression
Marginally linear features
Alignments of major stream or other water body segments (water visible) → a
Alignments of minor stream segments (water not visible) → b
Alignments of tonal features not fitting designations A or B → c
0 10 20 30 40 50 KM
Lineament interpretation by W.S. Kowalik
Base map of Pa by U.S.G.S. at 1:1,000,000
Images interpreted:
ID No. Date
1. 1407-15300-7 3 Sep 73
2. 1407-15302-7 3 Sep 73
3. 1046-15295-7 7 Sep 72
4. 1244-15312-7 24 Mar 73
5. 1459-15221-7 25 Oct 73
6. 1045-15240-7 6 Sep 72
7. 1495-15232-7 30 Nov 73
8. 1080-15183-7 11 Oct 72
9. 1080-15185-7 11 Oct 72
10. 1079-15124-7 10 Oct 72
11. 1079-15131-7 10 Oct 72
1
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Figure 9. Lineaments map of Pennsylvania
(W. Kowalik and D. Gold, 1975).

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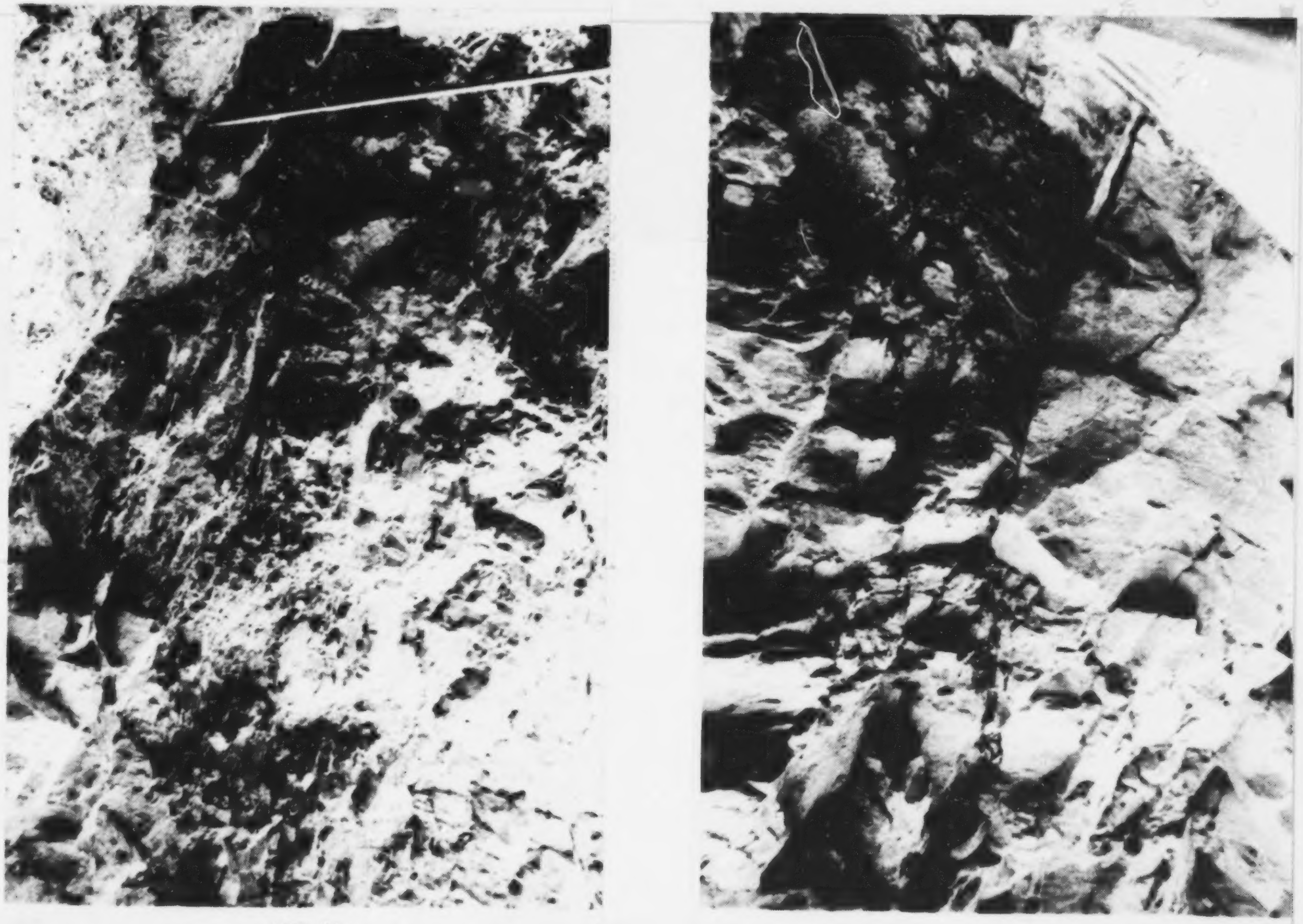

AUG 1970

AUG 1970

(a) (b)

Figure 10. Dolomite located immediately adjacent to a zone of fracture concentration (a) and intensely fractured dolomite along a zone of fracture concentration revealed by a fracture trace (b). No fault offset is shown in the outcrop of highly shattered rock.

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The combination of lithology, regional and local fold, fault, and joint structures, together with the character and distribution of overburden sediments, land surface topography, climate, and vegetation, provides the hydrogeological and geochemical framework of the Eastern Coal Province. Tied to the hydrogeological and geochemical framework are many influences, such as the occurrence, movement, and quality of groundwater, and the hydrologic budgets and flow systems of groundwater, as well as streamflow behavior. These basic elements combine in various and complex ways. When surface mines are placed in settings that combine the basic elements above, the mines create an often substantial environmental impact on the hydrogeological and geochemical framework.

The physical and chemical principles governing soil water and groundwater movement and quality remain constant in all mining regions; however, the variable mix of the controlling physical and geochemical elements that are involved make for a myriad of field expressions. The uninformed and inexperienced observer can become confused by this variable mix.

Some of these basic principles are reviewed in Volume 4, - Mine Hydrology; however, the application of these principles in premining planning investigations will remain the responsibility of the reader. It is the reader who must untangle this geological complexity and who must make judgments about which elements are most important at a particular mine site. In both the exploration and mine planning stages the reader must consider site-specific and regional geological controls, and geochemical and hydrogeological controls.

GEOMORPHIC COMPONENTS

In the planning of surface mining operations, there are two major categories of important geomorphic components: topographic elements and drainage elements. The topographic elements include landforms, relief, elevation, slope, and exposure. The drainage elements include stream-course delineation, drainage and subdrainage basin delineation, drainage patterns, forms, and texture. A brief discussion of the importance and evaluation of these factors is provided below (Stranberg, 1967).

Topographic Elements

The topographic elements (landforms, relief, elevation, slope, and exposure) have a major influence on surface mining operations. Topographic elements provide clues about the bedrock stratigraphy and structure, and the distribution and character of overburden sediments. They provide information about what governs surface runoff, and about the distribution of groundwater recharge, and they also show the discharge areas that mining is likely to impact. This and other information helps planners to set limits on mining method and mine layouts as well as on sediment control practices. The importance of topography on the hydrogeological setting is reviewed in Volume 4, Mine Hydrology, while the influence of topography on post-mining uses of the land is reviewed in Volume 6, Mine Land Planning.

In mine planning, 7-½ minute topographic maps are often adequate in the initial work. Fortunately, these are available for many coal mining districts. Typically, these maps are enlarged to a 1:200 or similar scale and are used as base maps in designing surface mines. These maps may indicate information such as: test holes, drainageways, diversion ditches, roadways, coal outcrops, structure contours on selected coal beds, property boundaries, limits of past mining, utilities, mine drainage treatment plants, sediment control basins, presence of water wells, springs, streams, and other information.

Frequently, a planner requires more precise topographic information than can be determined from 7-½ minute topographic maps, particularly from maps with a 10-ft contour interval. More precise maps will be useful to planners who design roadways, plan sediment and erosion control facilities, lay out water courses, and so forth. Points of importance to hydrogeological investigations can be surveyed in and added to existing base maps which increases their accuracy without requiring the expense of more refined topographic map making. Water level data, which is used to construct water table and potentiometric surface maps in low relief areas, should be based on precise ground elevation data rather than be interpreted from topographic maps because such maps may have a 5 foot error or more. The definitions of groundwater gradients, groundwater divide locations, directions of groundwater movement, rates and volumes of movement all depend upon accurate base maps and elevation data. Further, the topographic details can reveal much to a trained eye about the hydrological and geological setting of a proposed mine site. A brief description of drainage analysis illustrates this point.

Drainage Elements

Analysis and evaluation of the existing drainage system is an essential task in estimating the environmental impact that mining will have on that particular site. Drainage is controlled almost entirely by the physical character and altitude of surface features. Analysis of drainage systems helps the geologist to understand the dip and strike of the basic bedrock structure, and of the fault and fracture patterns that exist in that basic structure. An analysis of drainage systems also shows the resistance of the soil (and of the rock material) to weathering and erosion.

According to Stranberg (1967) in order to properly define the existing drainage system for a given site, the following tasks must be performed:

1. Stream-course delineation,
2. Drainage and sub-drainage basin delineation,
3. Drainage pattern and form analysis,
4. Drainage texture analysis, and
5. Slope and landform analysis.

A brief review of the methods used to perform these tasks has been provided by Stranberg (1967) and is reproduced with slight modification below.

Stream-Course Delineation--

Stream courses form the complete drainage pattern. All water bodies, rivers, streams, and drainage channels must be traced diagrammatically in order to be analyzed and properly reconstructed or advantageously modified. Existing watershed drainage patterns will influence any system for site drainage so it is important that planners consider hydrographic features when such a system is being developed.

Gullies and stream courses on topographic maps are marked in blue. Headwater runoff channels are found by studying contour lines. Contour lines crossing stream courses and large gullies form distinct "V" shapes. The apex of the V points toward higher ground.

Most gullies and smaller stream courses are not shown on topographic maps. They are classified as micro-relief features because they are too small to be shown at the contour interval to which the map is drawn. Depending upon resolution gullies and smaller stream courses can be seen on most aerial photographs, even those of very small scale.

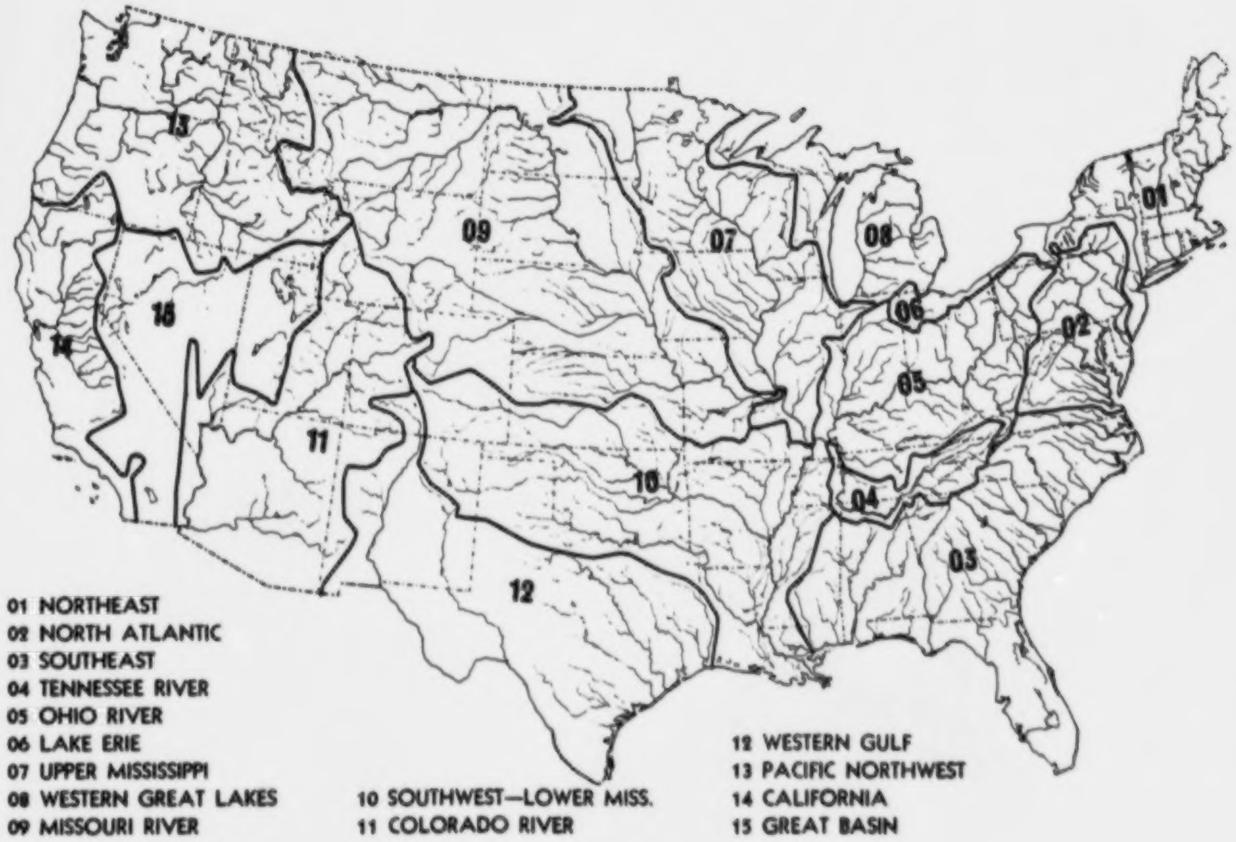
Drainage and Sub-Drainage Basin Delineation--

The drainage area has been defined as the area which contributes water to a particular channel or set of channels. It provides a limited unit of the earth's surface within which basic climate quantities can be measured and characteristic landforms described; it also provides a system within which a balance can be struck in terms of inflow and outflow of moisture, erosional energy and quality (Leopold and others, 1964). Thus, the drainage area, watershed or river basin (depending on the size of the area being investigated) is a logical basic unit upon which to base water quantity and quality control programs.

To date, land use planning efforts and certainly surface mining operations have had limited regard for geomorphic boundaries and factors. This disregard is partly due to the fact that geomorphic boundaries frequently do not recognize political boundaries, also, political subdivisions are seldom based on geomorphic considerations, except for major rivers, mountains, or other such features. However, there is a growing recognition in the planning profession that the watershed or drainage basin represents the logical geomorphic unit for planning purposes. This is illustrated by Figure 11 which shows the major drainage network and the 15 major drainage basins of the United States. Note the different drainage pattern forms that exist in separated parts of the nation.

Regional drainage is affected by several factors, including the initial slopes of the land surface, differences in rock hardness, bedrock structure, soil texture, topography, artificial waterways, vegetation, evaporation, climate, and the total amount of and frequency of rainfall. Regional drainage and type of landform are interrelated. An understanding of the drainage pattern helps the planner to better understand the significance of landforms.

Once the streams and other water courses have been delineated, one can locate the ridge lines separating these drainageways by examining the contour


01
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12
13
14
15
01 NORTHEAST
02 NORTH ATLANTIC
03 SOUTHEAST
04 TENNESSEE RIVER
05 OHIO RIVER
06 LAKE ERIE
07 UPPER MISSISSIPPI
08 WESTERN GREAT LAKES
09 MISSOURI RIVER
10 SOUTHWEST—LOWER MISS.
11 COLORADO RIVER
12 WESTERN GULF
13 PACIFIC NORTHWEST
14 CALIFORNIA
15 GREAT BASIN

Figure 11. Map of major river basins of the United States (Stranberg, 1967).

lines on the topographic maps or one can use stereoscopic photographs. After the ridge lines have been located, one can draw a solid line along the crests of the ridges to obtain the surface water drainage basin.

Drainage Pattern and Form Analysis--

Drainage patterns are classified by form and texture. Drainage pattern form (or shape) is governed primarily by bedrock structure. Six basic drainage pattern forms are generally recognized. These include:

1. Dendritic (branching like a tree),
2. Trellis,
3. Radial,
4. Parallel,
5. Annular, and
6. Rectangular.

Dendritic form--Figure 12 illustrates the dendritic form, which is by far the most common. Dendritic stream pattern forms indicate that the surface materials are relatively homogeneous. Such forms develop where bed rock does not protrude through the surface to block or deflect stream channels; these forms indicate flat-laying, uniformly resistant, usually sedimentary rock.

Dendritic forms may also develop over massive metamorphic rock or by superposition over complexly folded or metamorphosed rocks. The drainage pattern in Figure 12 is considered to be a classic example of dendritic drainage. Note that tributary branches join the next lower order streams at approximately the same angle. There are few, if any, abrupt bends in stream channels. Dendritic stream forms are so universal that if the basic form in any area is not dendritic, earth structure or landform conditions are unusual and probably warrant further study.

Trellis form--The trellis form resembles a vine on a garden trellis (see Figure 13). Primary tributaries are long and straight. They are often parallel to the main channel and to each other. Many short tributaries may join the larger channels at approximately right angles.

The trellis form is controlled by the structure of the rocks; it develops in folded or dipping rocks in the direction of strike. The long parallel tributaries follow the less resistant layers in the bedding. The short, stubby tributaries flow down the sides of the more resistant upturned beds. Tributaries will occassionally break through the intervening ridges approximately at right angles. The trellis pattern form suggests the tributaries' adjustment to truncated folding or steeply dipping beds. This pattern commonly develops on the flanks of anticlines or on tilted faulted rocks.

Radial form--The radial form may be compared with a wheel. The pattern may be either centrifugal or centripetal. In the centrifugal form, the hub of the wheel is higher, and the stream flows outward toward the rim. In the centripetal pattern, the rim is higher, and the stream flows inward toward the hub (see Figure 14).

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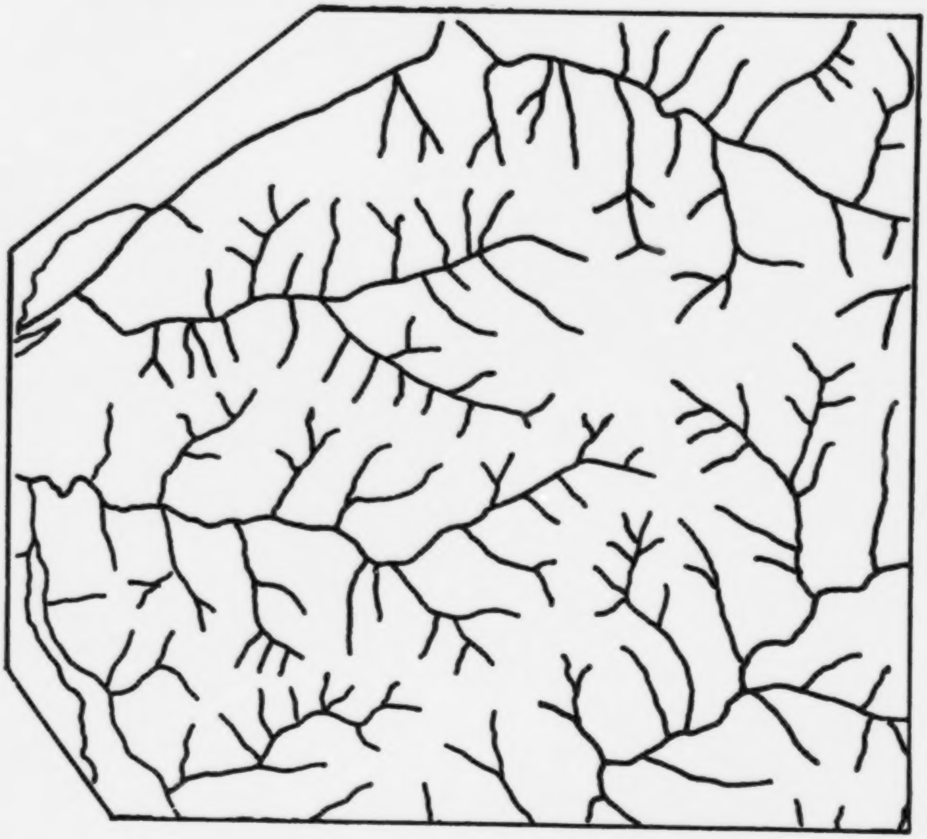

Figure 12. Illustration of dendritic drainage (Stranberg, 1967).

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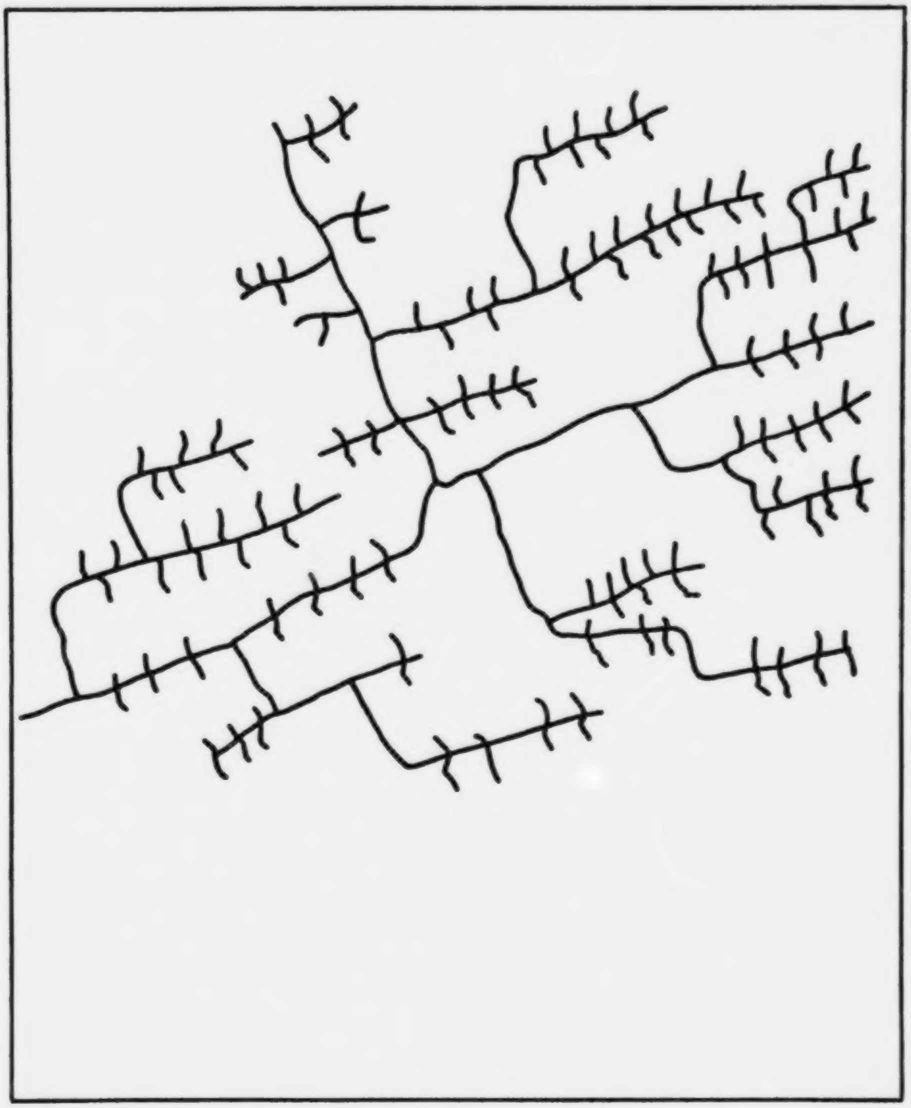

Figure 13. Illustration of trellis drainage (Stranberg, 1967).

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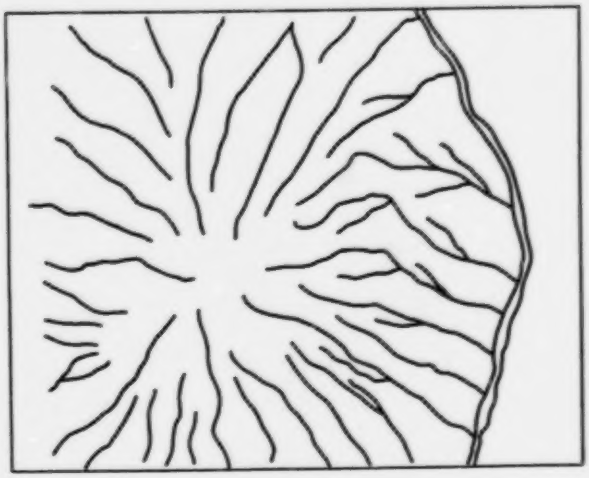

Figure 14. Illustration of radial drainage (Stranberg, 1967).

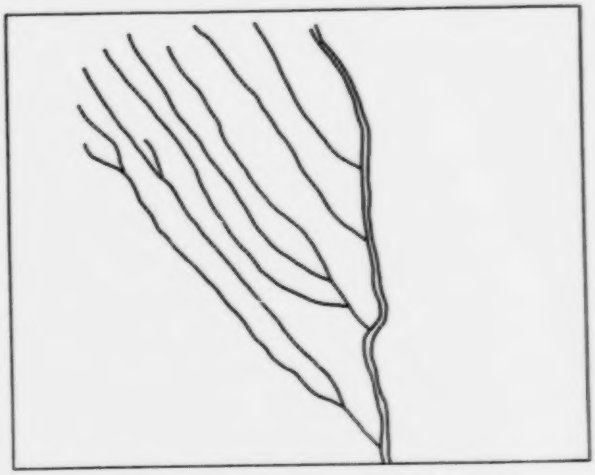

Figure 15. Illustration of parallel drainage (Stranberg, 1967).

Centrifugal (radial) forms develop when the water flows outward and downward from an elevated hill or dome. This form indicates that the bedrock is domed upward and more resistant strata occupy the core of the structure.

Centripetal (radial) forms develop when the water flows inward and down toward a basin. This form is more common in arid regions; it is also common in areas underlain by soluble bedrock, which causes the drainage either to run into a closed basin and to evaporate or go underground. Centripetal radial forms may indicate subsidence and structural basin formation or flow may be toward lakes that were formed by continental glaciation.

Parallel form--Tributaries flow parallel or nearly parallel to each other in this form; it resembles a horse's tail (see Figure 15). The tributaries join the main channel at nearly the same angle. This form sometimes indicates that a major fault extends at an angle across an area in which the bedrock is steeply folded. The tributaries follow beds in the less resistant rock. The main stream follows the fault. Parallel drainage can also result from parallel zones of fracture concentration, or meltwater channels that were formed in a side hill position parallel to a continental glacier that retreated down the regional topographic slope.

Annular form--Annular forms develop when stream courses adjust to flow around resistant domes (see Figure 16). This form (or a modification of the radial form) may develop if a dome has forced the layers of different resistance upward. This form is controlled by the shape of the topography and altitude of the bedrock. Tributaries that follow the less resistant layers may then develop, intersecting the radial channels at nearly right angles.

Rectangular form--Rectangular forms develop in areas where joints, faults, and zones of fracture concentration have developed in the bedrock (see Figure 17). Main channels contain abrupt bends. Streams join together at approximately right angles. Local differences in the composition of the bedrock may alter the form.

Other forms--In addition to the six basic drainage pattern forms, several less common forms exist. Many of these forms are modifications of the basic forms and each one may have special significance. The forms identified to date include:

1. Deranged form,
2. Subparallel form,
3. Contorted form,
4. Subdendritic form,
5. Anastomotic form,
6. Pinnate form,
7. Colinear form,
8. Dichotomic form,
9. Rectilinear form,
10. Swallow hole form,
11. Asymetrical form,

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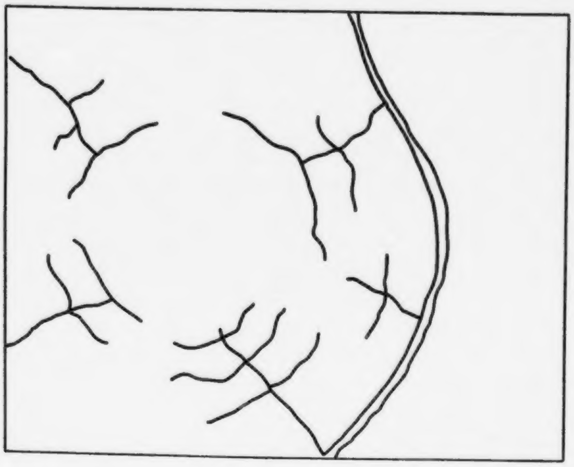

Figure 16. Illustration of annular drainage (Stranberg, 1967).

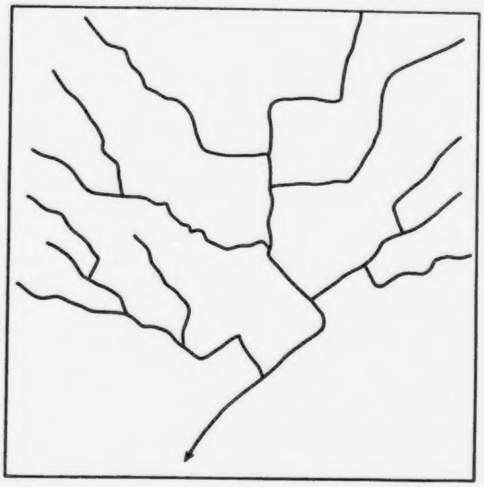

Figure 17. Illustration of rectangular drainage (Stranberg, 1967).

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12. Angulate form,
13. Illusory form,
14. Barbed form,
15. Braided form,
16. Anomalous form,
17. Thermokarst form,
18. Laundate form,
19. Yazoo form,
20. Kettle-hole form,
21. Elongated-bay form,
22. Recticular form, and
23. Phantom form.

A discussion of each of these forms is not feasible within the scope of this report. However, the importance of each form and the geologic situation it depicts should be recognized during the planning process. An excellent description of these forms can be found in Stranberg (1967).

Analysis of Drainage Texture--

Drainage pattern texture is governed primarily by (1) soil permeability--the ease with which water will infiltrate into the soil, and (2) water availability--the volume of water that is available to enter into the surface in a given period.

If the soil is only moderately permeable and only a small amount of rain strikes the surface in a given period of time, most of the water that does not evaporate will infiltrate. If an excessive amount of water (more than will evaporate or soak into the surface) reaches a level land surface or the land surface contains closed depressions, the excess water will pond. If the land surface slopes, the excess water will drain off.

Fewer drainage channels will be formed in permeable soils because more of the available water will soak into the soil. The smaller the number of drainage channels, the coarser the resulting drainage pattern.

Water flowing downhill seeks the easiest route, and the easiest route generally follows the steepest slope. If the steepest slope is interrupted by outcropping bedrock or more resistant beds, the flowing water may change direction. Loose soil will be washed away to create steeper slopes. If the surface soil is more cohesive so that it cannot be washed away easily, the stream channel will adjust and move toward looser soil or the channel will develop a different drainage texture.

Drainage texture means the number and spacing of streams within a drainage or subdrainage basin, and it consists of two major elements: stream density and stream frequency. Relative numbers for comparing these elements in different areas can be calculated.

The numerical ordering of drainage systems is an important concept associated with drainage texture. Numerical designation systems are useful because they indicate the relative position and location of drainage basins.

Horton (1945) has developed a simple method of ordering stream channels and drainage areas. Stream order is a measure of the position of a stream in the hierarchy of tributaries. This ordering is best described by using a sketch (see Figure 18). Given a map of certain scale, the first-order streams are those that have no tributaries. The second-order streams are those that have only first-order channels as tributaries. However, each second-order stream extends headward to the tip of the longest tributary it drains.

The third-order stream receives as tributaries only first- and second-order streams, and it also extends headward to the end of the longest tributary. It can be seen, then, that in practice, after the second-order channels are labeled and third-order channels identified, one of the previously marked second-order streams is renumbered to make it the headward extension of the third-order stream.

By using this method, it has been demonstrated that stream order is related to number of streams, channel length, and drainage area by simple geometric relationships; that is, stream order plots against these variables as straight lines on semilogarithmic paper. Table 1, which has been developed using these concepts, presents a summary of the number, lengths and mean drainage areas of various-sized river channels in the United States.

Stream or drainage density, which refers to the total length of all stream courses in a drainage or subdrainage basin, can be computed by calculating the quotient of the cumulative length of all streams (L) shown in the drainage basin and the total drainage area of the basin (A). The mathematical expression is:

$$L/A = D \tag{1}$$

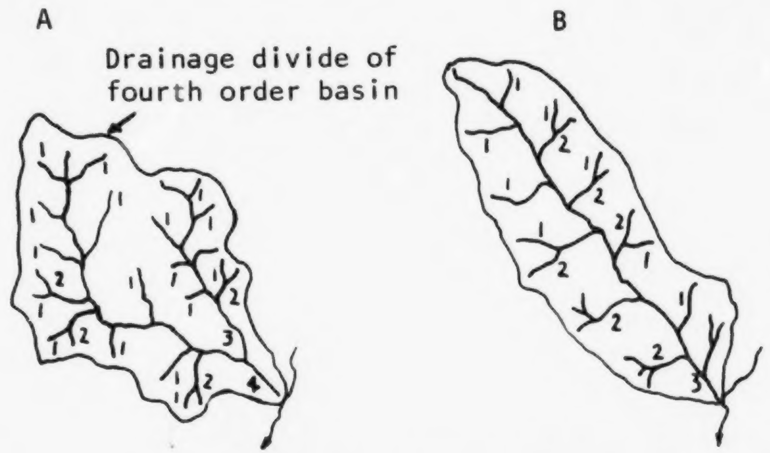
where L = total length of all stream courses in a drainage or subdrainage basin,
A = area of basin,
D = relative stream density number.

Stream frequency refers to the total number of streams in a drainage or subdrainage basin. Mathematically, stream frequency may be computed as:

$$N/A = F \tag{2}$$

where N = total number of streams in the basin,
A = area of the basin,
F = relative stream frequency order.

Relative numbers can also be calculated for comparing the ability of water to percolate (infiltrate) into the soil mantle. Relative infiltration numbers are calculated from stream density and frequency as:


A
Drainage divide of
fourth order basin
1
2
3
4
B

	Number of Streams	Order no.	Number of Streams	
Drainage area = 47	18	1	13	Drainage area = 44
Channel length = 77	4	2	7	Channel length = 72
	1	3	1	
Drainage density = 1.64	1	4	0	Drainage density = 1.64

Figure 18. Sketch to show order number of tributaries and other characteristics of the drainage net. Basin A and B have the same drainage density despite different shape (Leopold, Wolman and Miller, 1964).

TABLE 1. NUMBER, LENGTH, AND MEAN DRAINAGE AREA OF VARIOUS-SIZED RIVER CHANNELS IN THE UNITED STATES (EXCLUDING SMALLER TRIBUTARIES) (Source: Leopold and others, 1964)

Order*	Number	Average length (miles)	Total length (miles)	Mean drainage area, including tributaries	River representative of each size
1	1,570,000	1	1,570,000	1	
2	350,000	2.3	810,000	4.7	
3	80,000	5.3	420,000	23	
4	18,000	12	220,000	109	
5	4,200	28	116,000	518	
6	950	64	61,000	2,460	
7	200	147	30,000	11,700	Allegheny
8	41	338	14,000	55,600	Gila
9	8	777	6,200	264,000	Columbia
10	1	1,800	1,800	1,250,000	Mississippi
Total			3,250,000 (approx.)		

* The definition is that of Strahler: Order 1 is channel without tributaries; order 2 is channel with only order 1 tributaries, but includes only the length segment between junction upstream of order 1 channels and junction downstream with another order 2 channel.

$$I = DF \quad (3)$$

where I = relative infiltration,
D = stream density,
F = stream frequency

The larger I is, the more permeable the mantle. As used here, permeability refers to the internal drainage of the mantle.

Analysis of Slope and Landform--

In addition to the other slope analysis methods that were described in Volume 6, Mine Land Planning, the plotting of stream gradients and valley cross sections offers significant clues about the soil mantle, underlying rock type, and geological structure.

Gradient profiles of streams are constructed on maps by preparing templates that show the horizontal distance along the stream between contour lines. Stream-gradient profiles show the path of downward cutting action along a stream course. Almost all gradient profiles form a parabolic curve, as shown in Figure 19. These curves are constructed from topographic map data by (1) measuring off the linear distance between contour lines along the edge of a sheet of lined (or graph) paper; (2) transferring horizontal positions to appropriate vertical elevation positions (use lines on the plotting paper to represent datum elevations); and (3) connecting the transferred vertical/horizontal points with a smooth curve.

Stream-valley profiles are cross-sections, drawn at right angles to the axis of stream flow. An analysis of stream-valley profiles can frequently be used to locate the presence of consolidated beds along the sides of the stream valley. In addition, such an analysis is useful in delineating the width of the flood plain, as well as in locating thalwegs and natural levees (if they are present).

MAJOR PHYSIOGRAPHIC DIVISIONS OF THE EASTERN COAL PROVINCES

A brief, region-by-region summary of the major physiographic divisions occurring within the three eastern coal provinces is presented below. The summary includes a description of the major rivers and watersheds in these provinces. The information presented below has been adapted and summarized from a combination of published and unpublished background data which were compiled by Hittman Associates, Inc., for the Energy Research and Development Administration (Hittman, 1974).

Appalachian Region

The northeast/southwest-oriented Appalachian Region includes major portions of the Blue Ridge, Valley and Ridge, and the Appalachian Plateau Provinces as well as small portions of the Piedmont Province on the east,

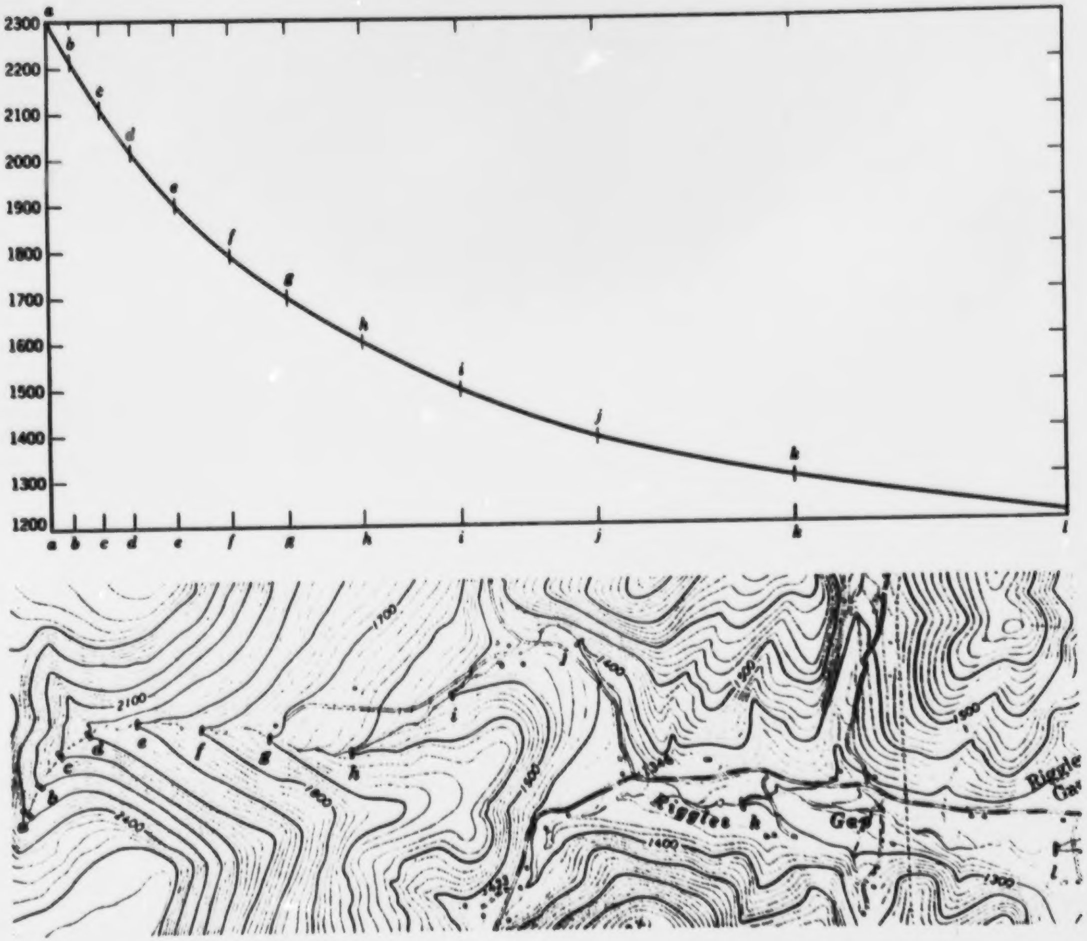


Figure 19. Construction of a stream gradient profile (Stranberg, 1967).

the Coastal Plain Province on the south, and the Lowland and Interior Low Plateau Provinces on the west (Figure 20).

The Blue Ridge Province is characterized by mature dissected mountains ranging from accordant altitudes in the northern section to subdued mountains in the southern section. Narrow and broad valleys with depths of 300 to 450 m (1000 to 1500 ft) below the ridge tops, common erosion surfaces, trellised drainage patterns, and incised rivers characterize the Valley and Ridge Province (Figure 20).

The Appalachian Plateau Province, making up the major portion of the region, is a submature to mature dissected broad plateau area of moderate to strong relief and this province contains several mountainous sections of strong relief. Relief may range from 60 to 90 m (200 to 300 ft) in some sections, 300 to 600 m (1000 to 2000 ft) in mountainous areas. The Central Lowlands Province is characterized as a low, mature dissected plateau with silt-filled valleys, cuestas, escarpments, and sinkholes (Fenneman, 1938). Relief ranges from low up to a few hundred meters. The streams that drain the region generally originate from the interior highlands. More than half of the Ohio River Basin is contained within the Appalachian Region. Figure 21 shows the major rivers and river basins in this region.

Topography in the Appalachian coal region ranges from gently rolling in central Alabama and northeastern Ohio, to mountainous in southern West Virginia, southwestern Virginia, and eastern Kentucky (USBM, 1976). As a general rule, the steepest slopes and greatest relief occur in Central Appalachia, which is mountainous, followed by Northern Appalachia, best described as rolling-to-hilly, and Southern Appalachia,where gently rolling terrain predominates. Topographic relief for the region, depicted in Figure 22, ranges from 760 m (2500 ft) in southwestern Virginia, to 90 m (300 ft) in parts of Ohio and Alabama. Figure 23 shows the status of topographic mapping for Appalachia.

Qualitatively, most mining in Central Appalachia takes place on steep slopes, defined here as natural ground slope angles greater than 17 degrees. Natural ground slope angles as high as 35 degrees have been observed at some active mines in southern West Virginia.

Slope angles in Northern Appalachia are more gradual, with angles of 10-18 degrees the rule at active mines. There are some very steep slope areas in the Northern Appalachia coal region, but available data suggest that most of the surface mining activity takes place in rolling and hilly terrain. Topography at mines in south-central Tennessee and central Alabama is best described as gently rolling, with natural ground slope angles less than ten degrees as the general rule.

Eastern Interior Region

In the Eastern Interior Region, the major physiographic provinces are the Central Lowland and the Interior Low Plateau Provinces (Figure 24). Included in these provinces are the states of Illinois, Indiana, and central and western Kentucky.

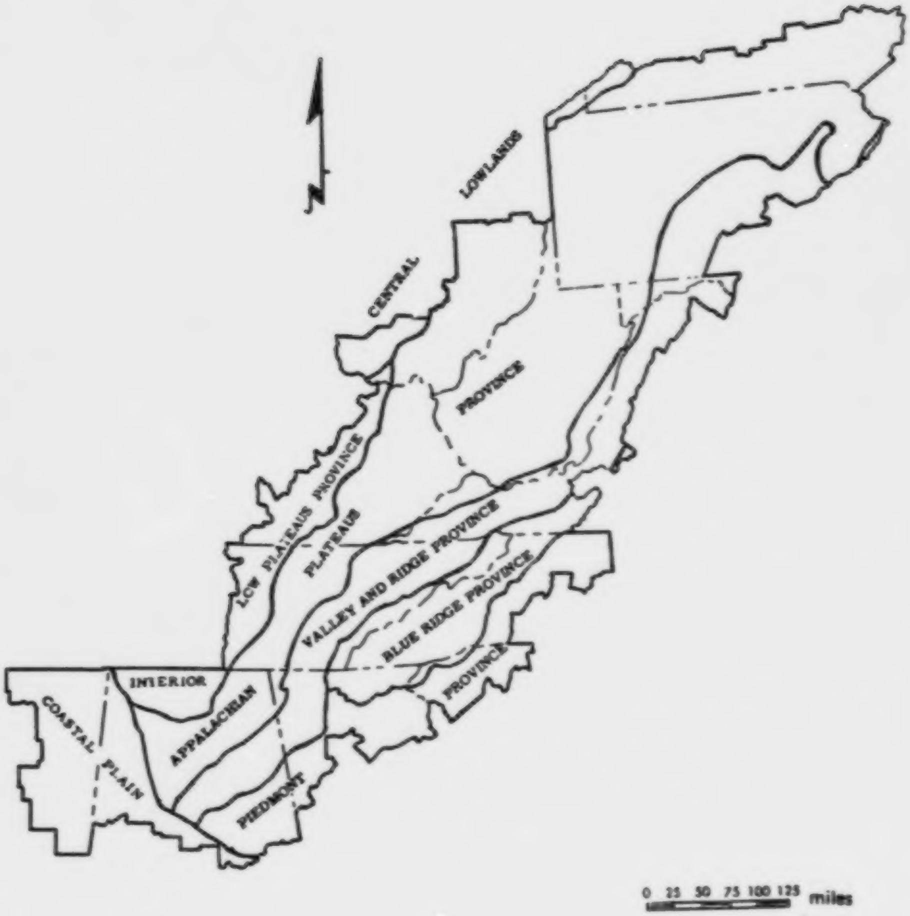

LOWLANDS
CENTRAL
PROVINCE
LOW PLATEAUS PROVINCE
PLATEAUS
VALLEY AND RIDGE PROVINCE
BLUE RIDGE PROVINCE
PROVINCE
INTERIOR
COASTAL
PLAIN
APPALACHIAN
PIEDMONT
0 25 50 75 100 125 miles

Figure 20. Physiographic provinces in the Appalachian Region (Fenneman, 1938).

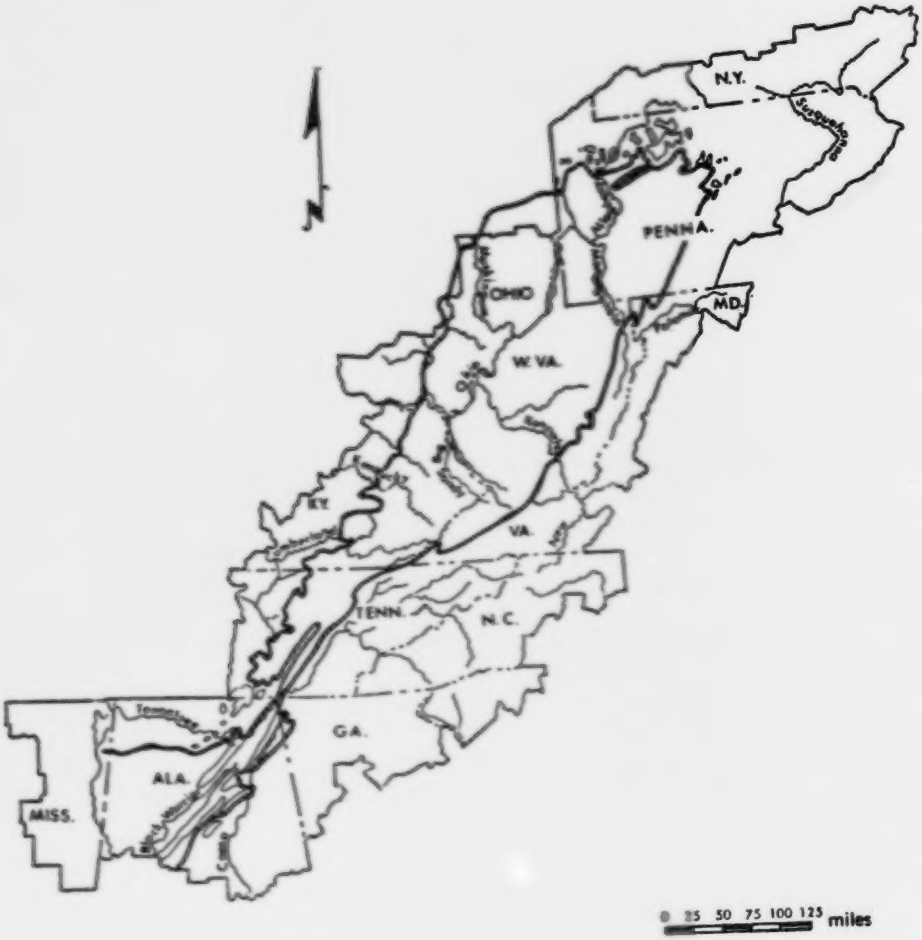

N.Y.
PENNA.
OHIO
MD.
W.VA.
KY.
VA.
TENN.
N.C.
GA.
ALA.
MISS.
0 25 50 75 100 125 miles

Figure 21. Major rivers of the Appalachian Region (ORBCC, 1968).

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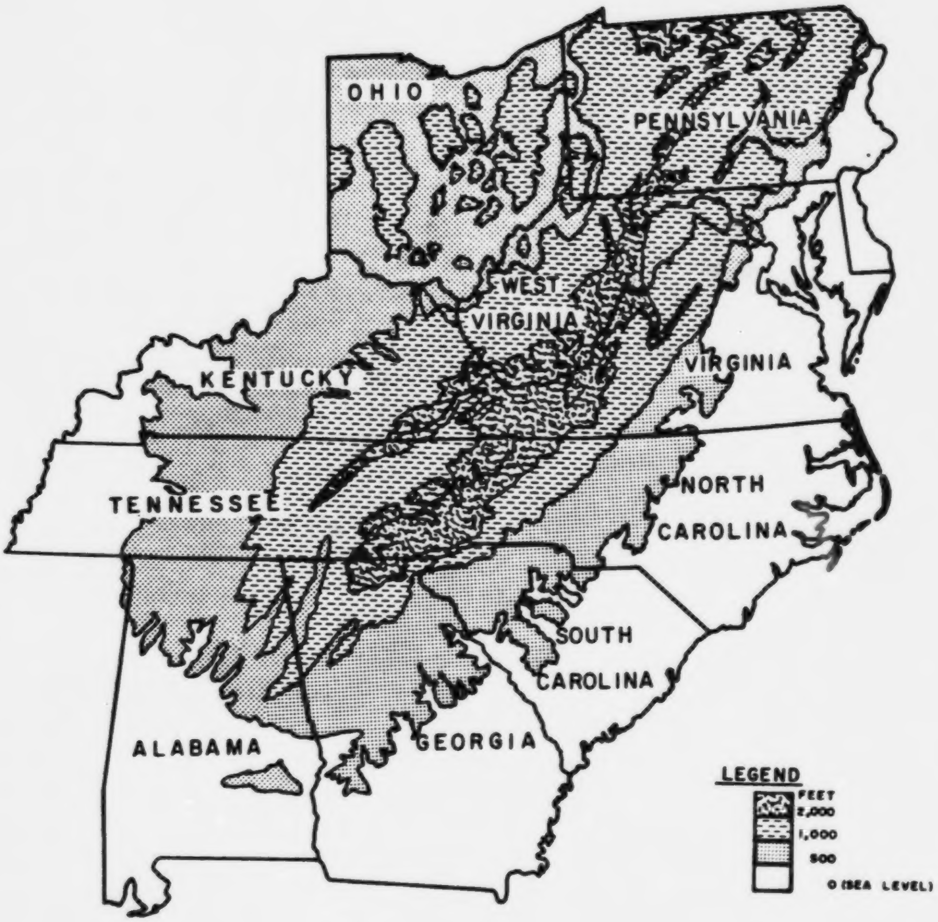
OHIO
PENNSYLVANIA
WEST VIRGINIA
KENTUCKY
VIRGINIA
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ALABAMA
GEORGIA
LEGEND
FEET
2,000
1,000
500
0 (SEA LEVEL)

Figure 22. Topographic relief in Appalachia (USBM, 1976).

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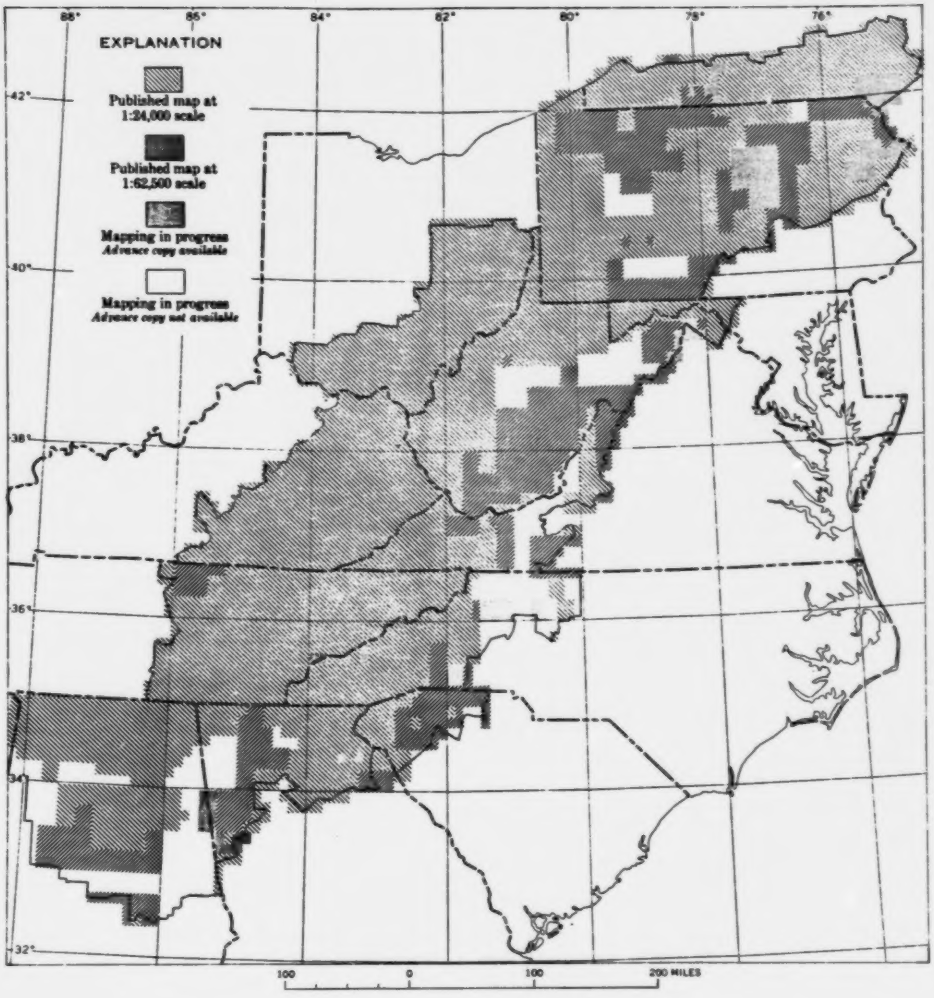
88°
86°
84°
82°
80°
78°
76°
42°
40°
38°
36°
34°
32°
EXPLANATION
Published map at 1:24,000 scale
Published map at 1:62,500 scale
Mapping in progress
Advance copy available
Mapping in progress
Advance copy not available
100
0
100
200 MILES

Figure 23. Status of topographic mapping in the Appalachian Region (USGS, 1968).

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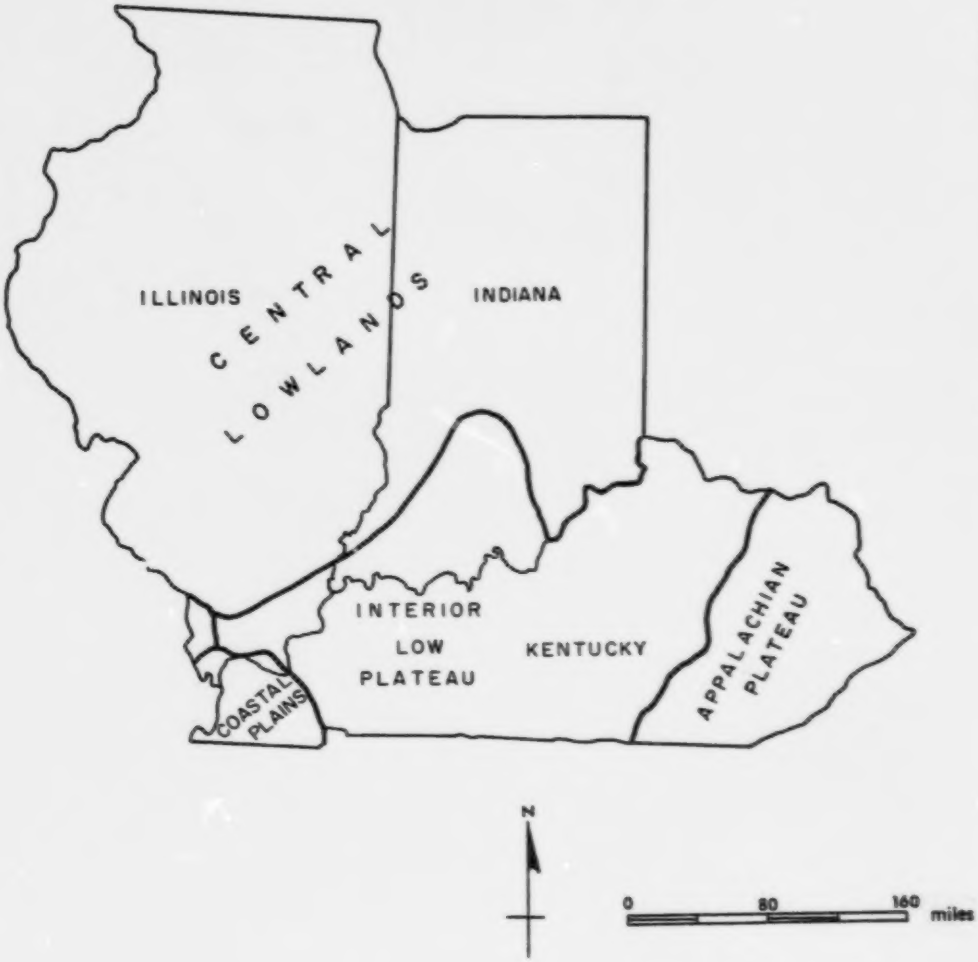
ILLINOIS
CENTRAL LOWLANDS
INDIANA
INTERIOR LOW PLATEAU
KENTUCKY
APPALACHIAN PLATEAU
COASTAL PLAINS
N
0
80
160
miles

Figure 24. Physiographic provinces of the Eastern Interior Region (Fenneman, 1938).

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The characteristic relief of the Eastern Interior Region differs markedly from the strongly dissected Appalachian Region which has moderate to strong relief. The Eastern Interior Region displays a surface of small relief, with a prevalence of morainic topography, lakes, swamps, and sandy outwash deposits in the northern portion, all of which become relatively insignificant in the southern portion (Fenneman, 1938).

The Fenneman maximum extent of the Pleistocene glaciation coincides with the southern border of the Till Plains Section in southern Illinois. Although the major portion of the Eastern Interior Region lies in the Central Lowland and Interior Low Plateau Provinces, the physiography is complex as a result of the meeting of the Ozark Plateau and Coastal Plain Provinces in southern Illinois (Figure 24). The major portion of the Eastern Interior Region in central and southern Illinois and southwestern Indiana, lies in the Till Plains Section. The Ozark Plateau and Coastal Plain Provinces include only a minor portion of the area. Major rivers are shown in Figure 25.

Elevations range from about 137 m (450 ft) in the lowest valley floors, up to 300 m (1000 ft) or more, on the highest uplands. Stream valleys in southern Illinois are 30 m (100 ft) or more below the adjoining uplands. Figure 25 shows the major rivers (and river basins) in the region.

The Interior Coal Province has a generally flat to rolling topography of gentle relief. There are some eroded mountains in eastern Oklahoma and western Arkansas known as the Ouachita and Bottom Mountains. The maximum elevation is 853 m (2,800 ft) above sea level. There are numerous scenic rolling hills, such as the Ozarks in Missouri and Arkansas, plus steep bluffs along many of the rivers and broken hills in southern Illinois, Indiana, and western Kentucky. The elevation of most of the area is less than 215 m (700 ft).

Western Interior Region

Missouri--

Northern Missouri lies in the Dissected Till Plains (Figure 26). The terrain is mostly rolling to hilly but some broad ridgetops are nearly level to undulating. Stream valleys are broad and have steep slopes along the valley borders. Elevations range from 215 m (700 ft) in the lowest valleys up to 335 m (1100 ft) on the highest ridges.

Northeastern Missouri occupies the nearly-level-to-gently-sloping silt-mantled old till plains sometimes referred to as the central claypan area (Austin, 1972). Stream valleys are narrow and quite shallow; the elevations range from 230 to 290 m (750 to 950 ft), then increase gradually from south to north. Local relief ranges from a few feet to a few tens of feet.

Southwestern Missouri consists of gently sloping to rolling dissected plains, underlain by sandstones, shales, and limestones; thin surficial loess deposits occur in the northernmost portions. Southern Missouri exhibits sharply dissected limestone plateaus which have narrow rolling ridgetops that break sharply to steep side slopes. In the westernmost portions of the Ozark

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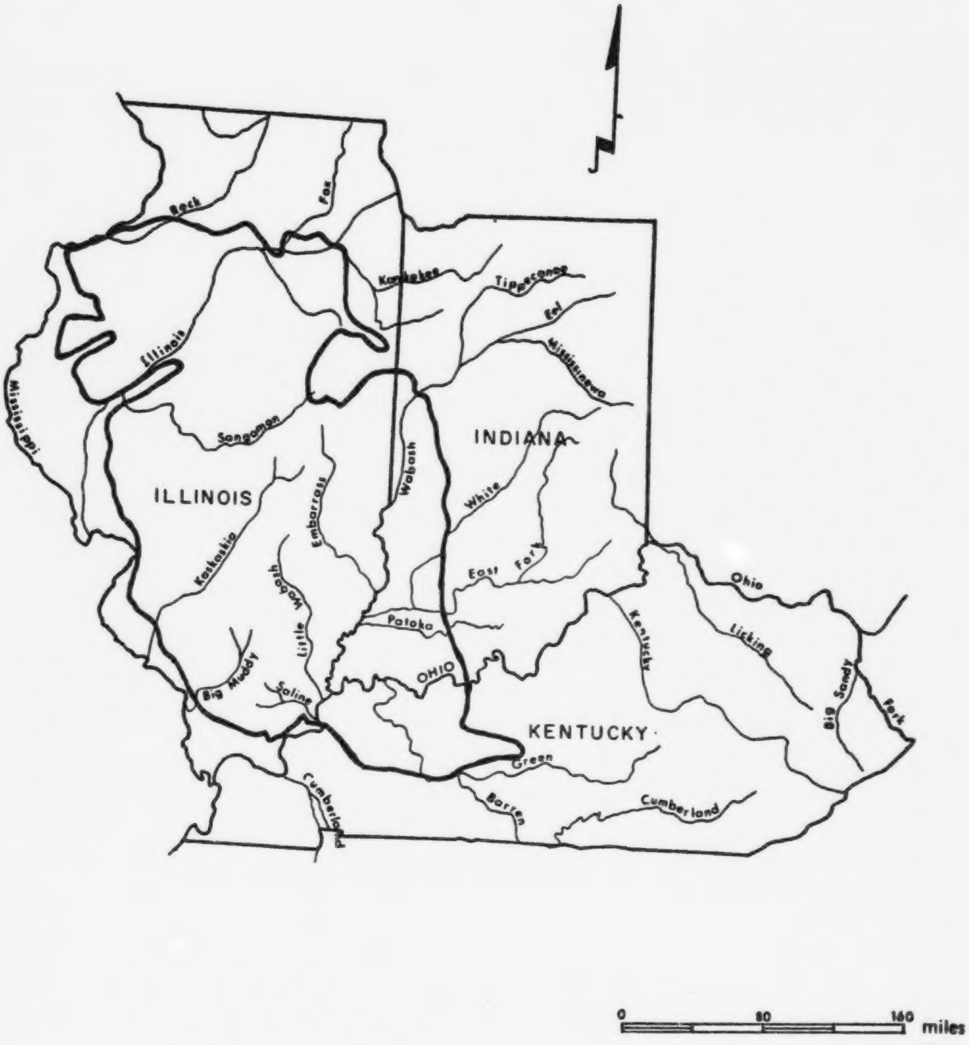
Rock
Fox
Kankakee
Tippecanoe
Eel
Mississinewa
Illinois
Mississippi
Sangamon
INDIANA
ILLINOIS
Wabash
White
Embarrass
Kaskaskia
Little Wabash
East Fork
Patoka
Ohio
Kentucky
Licking
Big Muddy
Saline
OHIO
Big Sandy
Fork
KENTUCKY
Green
Barren
Cumberland
Cumberland
0
80
160
miles

Figure 25. Major rivers of the Eastern Interior Region (Geraghty, 1973).

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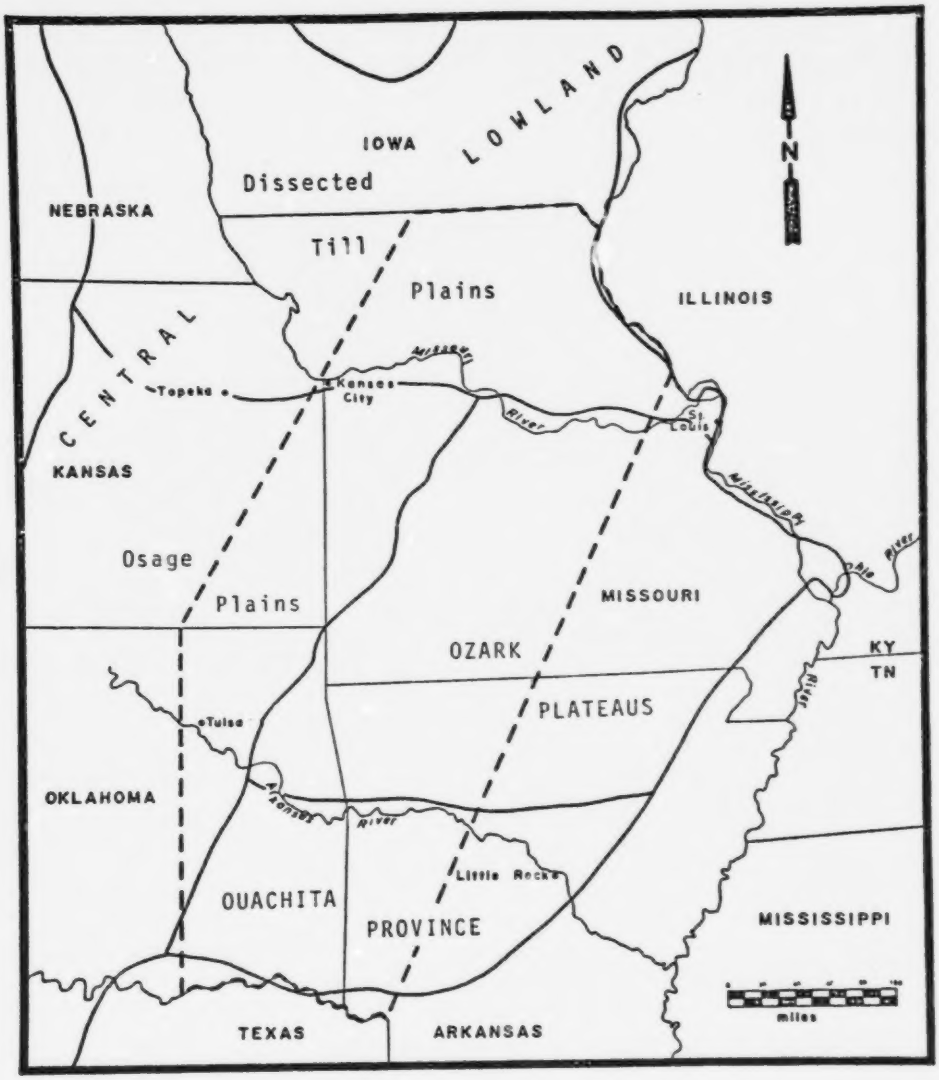
N
IOWA
Dissected
Till
Plains
CENTRAL
LOWLAND
NEBRASKA
ILLINOIS
Missouri
Topeka
Kansas City
River
St. Louis
KANSAS
Mississippi R.
Ohio River
Osage
Plains
MISSOURI
OZARK
PLATEAUS
KY
TN
Tulsa
OKLAHOMA
Arkansas River
River
Little Rock
OUACHITA
PROVINCE
MISSISSIPPI
miles
TEXAS
ARKANSAS

Figure 26. Physiographic provinces and sections in the Western Interior Region (Fenneman, 1931).

Highland, remnants of gently sloping plateaus are seen. Stream valleys are narrow with steep gradients, particularly in the upper reaches. Elevations range from 150 to 460 m (500 to 1500 ft).

Kansas, Oklahoma, and Arkansas--

Eastern Kansas and Oklahoma consist largely of the gently sloping-to-rolling, dissected plains (Cherokee Prairies), which are underlain by sandstones, shales, and limestones (Figure 26). Elevations range from 120 to 390 m (400 to 1280 ft). The rather large stream valleys are about 30 m (100 ft) below the adjacent uplands. The coal-bearing areas in southeastern Oklahoma lie partly in the Ouachita Mountains. The valley floors are generally narrow, with steep gradients; elevations range from 90 m (300 ft) on valley floors, up to 820 m (2700 ft) on mountain peaks.

Western Arkansas characteristically exhibits wide terraces and floodplains bordering the Ouachita River. In the mountain and ridge areas (Boston Mountains and Ridge areas) to the north of the Ouachita Mountains, elevations range from 90 m (300 ft) on the lowest valley floors, up to more than 820 m (2700 ft) on the ridge crests and mountain tops. The ridges in western Arkansas are underlain by slightly folded to level beds of sandstones and shales. The stream valleys are broad and smooth.

Figure 27 shows the major rivers and river basins in the region.

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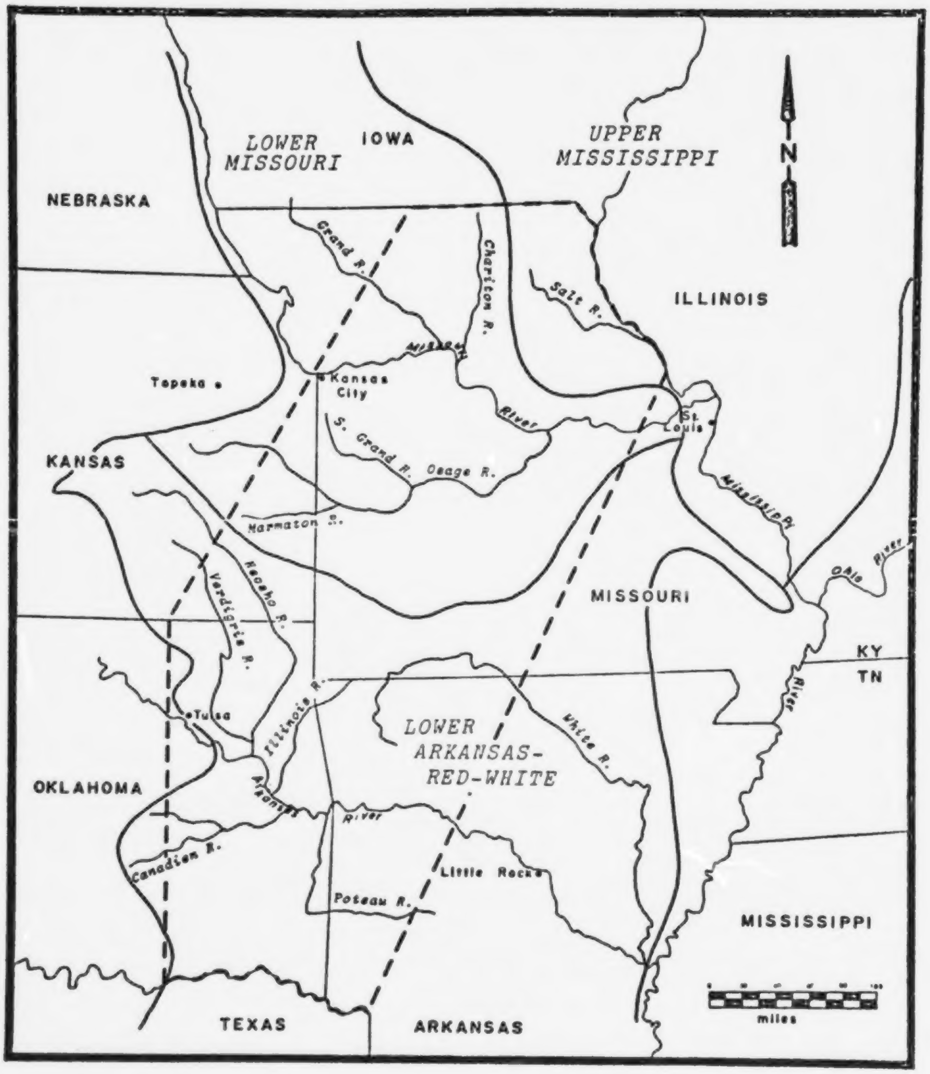
LOWER MISSOURI
IOWA
UPPER MISSISSIPPI
N
NEBRASKA
Grand R.
Chariton R.
Salt R.
ILLINOIS
Missouri
Topeka
Kansas City
River
St. Louis
S. Grand R.
Osage R.
KANSAS
Mississippi
Marmaton R.
Neosho R.
Verdigris R.
Ohio River
MISSOURI
KY
TN
River
Illinois R.
Tulsa
LOWER ARKANSAS-RED-WHITE
White R.
OKLAHOMA
Arkansas
River
Canadian R.
Little Rock
Poteau R.
MISSISSIPPI
miles
TEXAS
ARKANSAS

Figure 27. Major rivers and river basins in the Western Interior Region (Geraghty, 1973).

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SECTION 4

COAL GEOLOGY OF THE EASTERN COAL PROVINCES

OVERVIEW

The treatment of the geology of coal and associated strata and soils in the eastern United States is a multifaceted project that cannot be presented in complete perspective in one volume. The primary intent of the description of coal geology in this section is to provide a background for many of the hydrologic, engineering, and land use conclusions and recommendations that are in the other volumes of the manual. Geology is essential to many aspects related to the strip mining of coal, the restoration of mines, and the environmental impact of the mines during and following mining.

The paleoenvironments under which the coal was originally deposited are the first concern in this study. The paleoenvironmental aspect of sedimentation dictated the coal's original geographic distribution, physical properties, mineralogy, and sulfur content in relation to the surrounding strata, and the hydraulic properties that dictate their role as aquifers and confining beds. The present-day geology, topography, and climate are critical factors in controlling the existing groundwater and surface water flow patterns, the accessibility of the coal to various types of mining methods, and the type and success of reclamation methods that may be employed.

In the United States, for well over a century, State and federal agencies, universities, coal companies and various research groups have written numerous papers and reports about the stratigraphy and physical and chemical characterization of eastern coal and associated strata. Those reports, inventoried for this section, included reports of the U.S. Bureau of Mines (USBM), the U.S. Geological Survey (USGS), the Environmental Protection Agency (EPA), state geological surveys and bureaus of mines, and various universities, particularly The Pennsylvania State University. Because of the broad nature of the investigation, recent secondary summaries of the past and present work proved very useful; those summaries included the 1975 Keystone Coal Manual, the Carboniferous of the Southeastern United States (a symposium published by the American Association of Petroleum Geologists, 1962), and various contractor reports to federal agencies.

The primary objective in this section is to present a brief review of the general stratigraphy, topography, coal properties, and mining and reclamation methods that are characteristic of the several coal-bearing regions in the East. This information, then, will be integrated to formulate conclusions

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regarding the hydrologic aspects of surface coal mining and to make recommendations regarding site selection, analysis of groundwater flow systems, potential for acid mine drainage, and methods of minimizing adverse environmental effects.

OCCURRENCE OF SULFUR IN COAL

The presence of sulfur, in one form or another, is prominent among the mineral species known to occur in or with coal. Sulfur's presence is particularly well known primarily because of its detrimental effects on both air and water quality during the various phases of coal mining and utilization. Specifically, when high-sulfur coals are burned, the result is increased sulfur dioxide (SO_2) emissions, as well as significant acid mine drainage from mine areas, spoil banks, and refuse piles.

The three most common forms of sulfur in coal are organic, pyritic, and sulfate sulfur. The total sulfur content of coals, by seams and geographic regions, is well documented (by the U.S. Bureau of Mines (USBM) Information Circular (IC) 8680, 1975) for most coal mining areas in the United States.

Less is known about the distribution of pyrite (iron sulfide) within strata associated with high sulfur coal; the pyrite distribution is important in forecasting the potential for acid mine drainage that results from strip mining. There is evidence, however, that the total sulfur, alone, is not directly correlated to the production of acid mine drainage. Other factors also come into play: pyrite grain size, alkalinity of soil water and ground water in contact with pyrite, and more. The relationships of those factors to coal mine drainage are discussed in greater detail in Volume 4 - Mine Hydrology and Volume 5 - Mine Drainage Management and Monitoring. In addition, other discussions can be found in Caruccio and Parizek (1967), Caruccio (1970), Caruccio and others (1977), and Hornberger and others (1980).

Organic sulfur is distributed throughout the coal as part of its molecular structure. Mechanical cleaning and processing of coal does not remove this sulfur. In most cases, therefore, organic sulfur is contained unaltered when the coal is burned. However, because of the stability of organic sulfur in the coal, it does not contribute to acid mine drainage. Generally, organic sulfur is found in increased proportion in low-sulfur coals.

Sulfate sulfur, in fresh coal, is normally very low (less than .05 percent) and, in itself, it is not an important contributor to acid mine drainage. Sulfate sulfur is commonly contained within the mineral gypsum, which occurs as a secondary vein and cleat filling. Weathered coals, however, exhibit higher sulfate contents, resulting from the oxidation of iron sulfide (pyrite) into ferrous and ferric sulfate.

Iron sulfide is, by far, the most important form of sulfur in coal from the standpoint of the environment as well as usefulness. It can occur as either pyrite or marcasite; pyrite is usually the dominant form. Pyrite and and marcasite are the same chemically (FeS_2), but differ in physical structure.

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Since there is evidence that both react similarly and it is often difficult to distinguish one from the other, the total of the two minerals is usually referred to as pyritic sulfur. This sulfur is found in both macroscopic forms. In addition, the occurrence of pyritic sulfur may be of primary origin (deposited with the sediment) or due to secondary processes (replacement or void filling after deposition).

Macroscopic pyrite occurs in coal in the following forms: (1) veins that are usually thin and filmlike along vertical joints (cleats), but can be up to several inches wide and contain larger pyrite crystals; (2) lenses that are variable in shape and size but usually flattened and elongated in cross section, ranging in size from a fraction of an inch thick by several inches in diameter to several inches thick by hundreds of feet in lateral extent; (3) nodules or balls, highly spherical in shape and from inches to several feet in diameter; and (4) disseminated crystals and irregular aggregates that are extremely variable in size (Gluskoter and Simon, 1968).

Caruccio (1969), Caruccio and Parizek (1967), and Caruccio (1970) found that fine-grained pyrite exists either as developed crystals or as spherical clusters (framboidal pyrite). The framboidal-type pyrite is aligned with bedding and appears to be a primary deposit. Coarse-grained pyrite (>50 microns) most commonly occupies pre-existing plant structures and joints and appears to be a secondary deposit. Photomicrographs of various forms of sulfur are presented in a related EPA reference document (Caruccio and others, 1977).

When coals are mined, much of the pyritic sulfur previously isolated within the coal and associated strata is broken and exposed by the excavation process. Pyrite in shales and wasted coal becomes part of the spoil bank material that is left at the site. Coal that is hauled away is then subjected to mechanical crushing and cleaning. The size and distribution of pyrite will affect the amount that can be removed by conventional coal preparation methods. Coarse crushing may release the secondary pyrite found in lenses, bonds, cleats, and joints. Finely disseminated pyrite can be removed only by fine crushing and special treatment (Walker and Hartner, 1966).

Separated waste material, usually consisting of low grade coal, slate, shale, and pyrite, then becomes refuse. Spoil banks and refuse piles, therefore, represent new geologic deposits in which the pyrite is distributed in a new, and more detrimental, manner. In western mining regions, this refuse is returned to the mine sites for burial. Some abandoned mines, that otherwise would not produce poor quality mine drainage, do so in response to the disposal of wastes containing above normal concentrations of pyrite.

Frequently, there may be, within a mining district, alternative mine sites that are nearby and available. These sites may contain soil or overburden strata that are geochemically more favorable. Wherever the opportunity exists, planners should give more attention to such alternative sites. These sites could reduce both the pollution load to be treated during mining and the seriousness of pollution in local groundwater and tributary streams after mines are abandoned.

PALEOENVIRONMENTS

It is well known that the deposition and transformation of organic material to the various forms of coal most commonly occurs in poorly drained swampy environments that were climatically suited to high organic productivity. Extensive swampy areas that remained under stable geologic conditions for long periods of time developed thick organic sediments that later formed large coal beds, such as the major coal beds in the Appalachians and in the Interior Basins. Swampy conditions often represent a transitional, near coastal environment; so, particularly during the Pennsylvanian age, many of the coal-producing periods in given locations were really intermediary stages in the cycle of transgressive or regressive seas (or prograding or eroding shorelines). This fact is evident in the repeating sequence (cyclothems) of strata found in many of the eastern coal basins, particularly in the Interior Basins and parts of the Appalachians.

The changes in environments over geologic time are also expressed by often abrupt lateral variation, or facies changes, of strata on a regional basis. While this lateral variation is interesting from the standpoint of occurrence of coal, it takes on added importance in terms of the sulfur content and acid-producing potential of the deposits, the potential presence of calcareous strata that might offset acid reactions, and the distributions of aquifers and confining beds associated with coal.

The cyclical patterns of sedimentation in coal-related strata have been characterized for different geographic and geologic areas. Part of this characterization generally consists of the development of an "ideal" cyclothem, with notes as to the frequency of variation from this ideal. While most investigators recognize the concept of cyclothems, the positions of the basal and upper units representing a single cycle differ. In the past, the recognition of cyclothems has been important in identifying and correlating the occurrence of valuable coal seams. More recent investigations have examined cyclothems in light of their depositional environments as they vary in time and space.

Cyclothems are well developed and are traceable over wide areas in the younger rocks of the Dunkard Basin (eastern Ohio, southwest Pennsylvania, and northwest West Virginia), and in the shelf sediments of Ohio, and in western portions of West Virginia and Pennsylvania (Branson, 1962). Cyclothems in Pennsylvanian-aged rocks east of this area are less well defined or are absent. Of the 13 cyclothems identified in the Allegheny Group in Ohio, the ideal normal cyclic sequence in the group, in most cases incomplete, is as follows (Branson, 1962):

marine shale or limestone
coal
underclay
fresh-water limestone
sandstone and shale

There are approximately 50 recognized cyclothems in the Eastern Interior Basin. More than 24 cycles have been mapped as delta and associated alluvial plain sequences (Wanless and others, 1970). The initiation, growth, and abandonment of these delta lobes into a slowly subsiding basin resulted in the development of the cyclothems and their complex vertical and horizontal arrangement (Pryor and Sable, 1974). An example of an ideal cyclothem in the Eastern Interior Basin is presented in Figure 28. This diagram includes a lithologic description of deposits. Geologists disagree concerning the position of the basal unit of the sequence (either 1 or A in Figure 28), and therefore, as to the order and interpretation of the depositional environments. The relative positions of the strata, however, are firmly fixed.

Recent investigations by Williams and Keith (1963), Ferm and Williams (1962, 1964, 1965), Caruccio (1968, 1970), Caruccio and Parizek (1967), Caruccio and Ferm (1974), and Caruccio and others (1977) indicate that consideration of the depositional environment is critical when scientists attempt to identify what the content and the reactive nature of the sulfur associated with the coal is likely to be. Detailed studies by Williams (1960) in western Pennsylvania indicated a transgressive paleoenvironment in the Allegheny Group of the Pennsylvanian-aged rocks. These rocks were found to grade upward from marine to more continental in origin. In addition, Ferm and Williams (1960) showed that this transgression is expressed as facies changes, grading from marine, in western Pennsylvania, to brackish farther east.

Studies by Caruccio (1968, 1970) and Caruccio and Parizek (1967) showed that the mode of occurrence of pyrite within the coal strata is of greater importance than simply the total sulfur content in determining the production of acid by leaching. Framboidal pyrite, attributable to the mode of primary deposition, was found to result in much higher acid production that the secondary type of pyrite. It is expected that the coals associated with lower delta, or more marine environments, will contain pyrite of a more reactive nature than coals deposited in a fluviodeltaic, or more continental location. This contention is substantiated in an experiment (Caruccio and others, 1977). In it, a number of Kentucky coals taken from differing paleoenvironmental settings were leached and the geochemical impact of the surface mining of a particular coal on nearby surface and groundwater was noted. Hornberger, Williams and Parizek (1980) show that this generalization may not be valid and that other controls on acid production also are involved.

Recent investigations have produced both regional and detailed reconstruction of carboniferous paleoenvironments. For example, many investigators have characterized the regional interpretation of sedimentation in the central Appalachians (during the middle to upper Pennsylvanian Age) as controlled largely by transgressing or regressing deltaic systems.

Figure 29 illustrates a conceptual view of Allegheny depositional environments in the central Appalachians. Marine limestones represent offshore carbonate tidal islands and barriers, and the associated red and green shales formed in oxidized clay-floored lagoons. Sandstones and orthoquartzites are apparently bay barrier deposits, often grading into dark gray shales or back barrier sediments. Coal-bearing strata, dark shales, and graywacke sandstone represent fluviodeltaic depositional environments (Ferm, 1974).

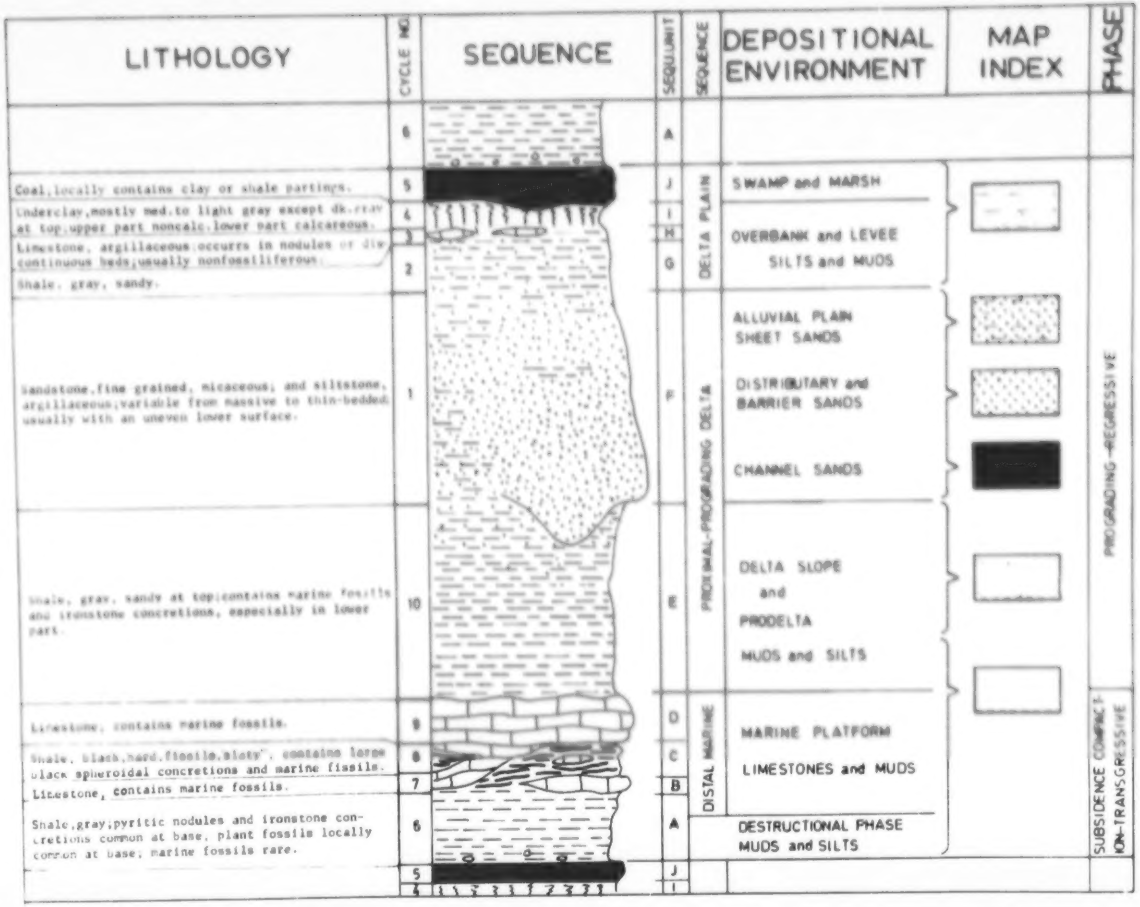
LITHOLOGY
CYCLE NO.
SEQUENCE
SEQ.UNIT
SEQUENCE
DEPOSITIONAL ENVIRONMENT
MAP INDEX
PHASE
6
A
Coal, locally contains clay or shale partings.
5
J
Underclay, mostly med. to light gray except dk. gray at top; upper part noncalc. lower part calcareous.
4
I
Limestone, argillaceous; occurs in nodules or discontinuous beds; usually nonfossiliferous.
3
H
Shale, gray, sandy.
2
G
DELTA PLAIN
SWAMP and MARSH
OVERBANK and LEVEE SILTS and MUDS
Sandstone, fine grained, micaceous; and siltstone, argillaceous; variable from massive to thin-bedded usually with an uneven lower surface.
1
F
PROXIMAL-PROGRADING DELTA
ALLUVIAL PLAIN SHEET SANDS
DISTRIBUTARY and BARRIER SANDS
CHANNEL SANDS
Shale, gray, sandy at top; contains marine fossils and ironstone concretions, especially in lower part.
10
E
DELTA SLOPE and PRODELTA
MUDS and SILTS
PROGRADING—REGRESSIVE
Limestone, contains marine fossils.
9
D
Shale, black, hard, fissile, slaty, contains large black spheroidal concretions and marine fissils.
8
C
Limestone, contains marine fossils.
7
B
DISTAL MARINE
MARINE PLATFORM
LIMESTONES and MUDS
Shale, gray; pyritic nodules and ironstone concretions common at base, plant fossils locally common at base; marine fossils rare.
6
A
DESTRUCTIONAL PHASE MUDS and SILTS
SUBSIDENCE COMPACTION-TRANSGRESSIVE
5
J
4
I

Figure 28. Proposed sequence of strata and depositional environments for an ideal cyclothem (Pryor and Sable, 1974).

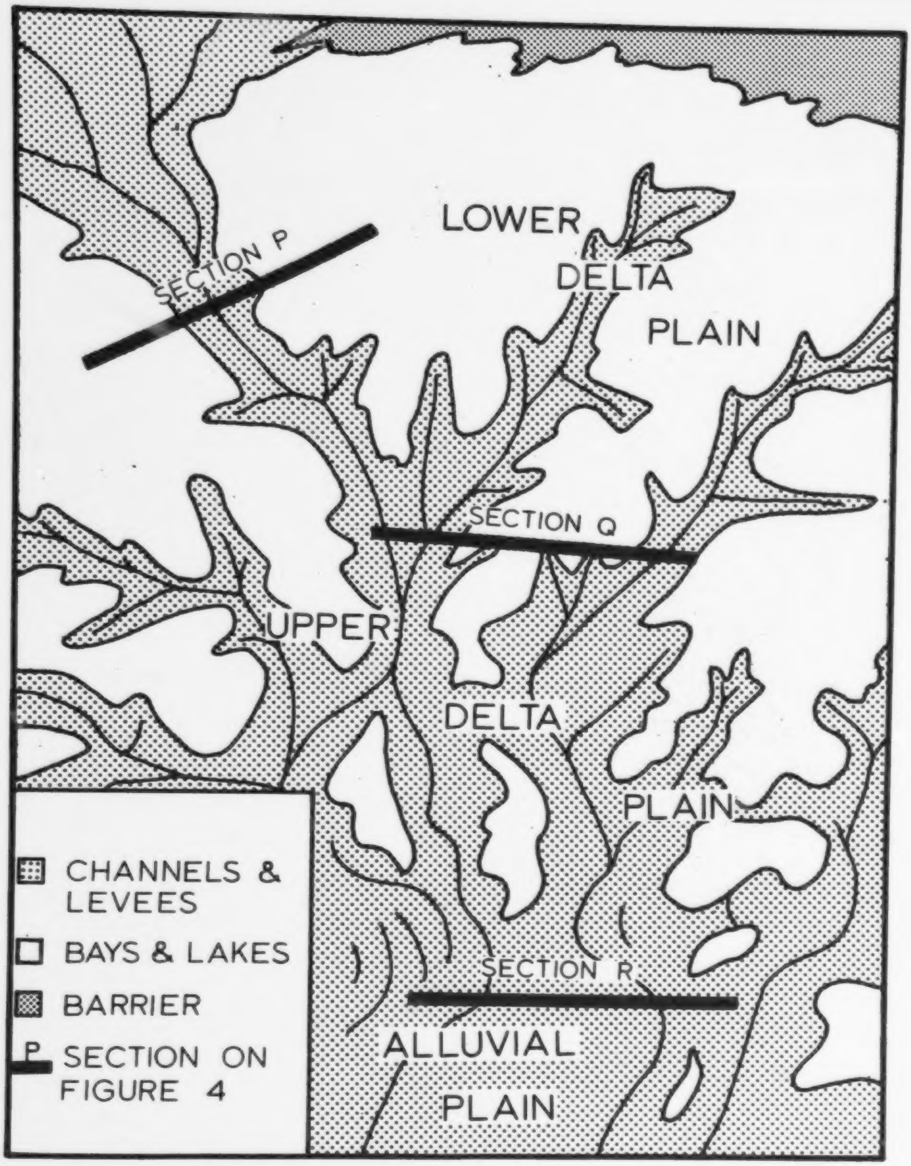
LOWER
DELTA
PLAIN
SECTION P
SECTION Q
UPPER
DELTA
PLAIN
SECTION R
ALLUVIAL
PLAIN
CHANNELS & LEVEES
BAYS & LAKES
BARRIER
P
SECTION ON FIGURE 4

Figure 29. Plan view of Allegheny depositional environments. The upper third of the diagram represents approximate Allegheny environments in northwestern Pennsylvania and northeastern Ohio. The central third is southwestern Pennsylvania, northern West Virginia, southwestern Ohio, and northeastern Kentucky. The southern third is central West Virginia (Ferm, 1974).

A typical example of this sediment distribution, in both map and cross-sectional view, is given in Figure 30. Useful criteria for recognizing depositional environments of sedimentation are summarized in Table 2.

Observers can infer the mineralogy of the coal, particularly of the sulfur species, by delineating whether a strata at a particular geographic and stratigraphic position was deposited under alluvial, upper delta, lower delta, or shoreline conditions. According to Caruccio's data then, one could expect the coals and rocks rich in the framboidal pyrite to be associated with the lower delta and barrier settings. Less reactive pyrite would be found more often in upper delta or alluvial plain deposits (Caruccio and Ferm, 1974). Hornberger, Williams and Parizek (1980) conclude by contrast that the presence or absence of calcareous materials are more important than the environment of deposition except as it influenced the presence or absence of calcareous deposits.

An abundance of pyritic sulfur in coal and overburden strata increases the probability of acid reactions that may significantly degrade surface- and groundwater quality in mining regions. Serious pollution problems, however, are not always inevitable. Calcareous shales, micritic carbonates, and clastic carbonates that may form lenses, nodules, or distinct beds <0.3 to 15.2 m (<1 to 50 or more ft thick), for example, may also be interbedded with acid-producing strata (Figure 31). These calcareous beds, depending upon their thickness and position within groundwater flow systems and with respect to the coal being mined (as will be discussed in a later chapter), may enrich soil water and groundwater in bicarbonate. The bicarbonate may either inhibit acid reactions and/or buffer and help neutralize acid mine drainage (Barnes and Romberger, 1968; Caruccio and Parizek, 1967; Waddell and others, 1980; Waddell, 1978). Bicarbonate may not only be derived from soil and overburden spoil deposits, but also from calcareous bedrock located below coal seams being mined. This deeper source of alkalinity is available to help neutralize acid mine drainage within surface mines, within groundwater flow systems below the mine, and in nearby tributary drainages receiving deeper groundwater (Parizek and Tarr, 1972).

Glacial drift, such as till, outwash, sand, gravel, loess, and lake sediments, frequently provides an added source of bicarbonate that can be highly effective in abating acid mine drainage (as is discussed in Volume 5, Mine Drainage Management and Monitoring). These deposits which result from continental glaciation, blanket coal-bearing bedrock strata throughout a significant portion of the eastern province, including Pennsylvania, Ohio, Indiana, Michigan, Illinois, Iowa, Kansas, Nebraska, and Missouri (Figure 32). Alluvial valleys which contain outwash sand and gravel from valley trains that are calcareous, and adjacent uplands which are blanketed by loess, may also contain appreciable amounts of limestone and dolomite fragments. These fragments produce alkaline soil water and groundwater.

Glacial drift may have been deposited by one of many major glacial advances ranging in age from Kansan to Wisconsinan (Figure 32). Or glacial drift may have been deposited by many substages of glaciation that represented smaller scale advances and retreats of individual lobes of ice.

Prolonged periods of weathering and erosion followed each glacial substage and glacial stage. Soluble calcite and dolomite minerals were often deeply leached 1.5 to 12.2 m (5 to 40 ft), and where drift deposits were

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TABLE 2. CRITERIA FOR RECOGNIZING DEPOSITIONAL ENVIRONMENTS
(Source: Caruccio and others, 1977)

Criteria for recognition	Depositional environments: Fluvial and upper delta plain	Transitional lower delta plain	Lower delta plain	Back-barrier	Barrier
I. Coarsening upward					
A. Shale & siltstone sequences	C-R	C	A	C-A	R-C
1. > 50 feet	N	R-N	C-A	C-A	R-C
5 to 25 feet	C-R	C-A	C-A	C-A	R-C
B Sandstone sequences	R-N	R-C	C-A	C	C-A
1. > 50 feet	N	N	C-A	R	C-A
2. 5 to 25 feet	R	R-C	C-A	C	C
II. Channel deposits					
A. Fine grained abandoned fill	R	C-R	A-C	C	R-C
1. Clay and silt	R	C-R	A-C	C	R-C
2. Organic debris	R	C-R	A-C	C-R	R
B. Active sandstone fill	A	C	C-R	C-R	C
1. Fine grained	C	C	C-R	C-R	C
2. Medium & coarse grained	A	C-R	R	R	C-R
3. Pebble lags	A	A	C	C-R	R-C
4. Coal spar	A	A	C	C-R	R-C
III. Contacts					
A. Abrupt (scour)	A	A	C	C	C-A
B. Gradational	C-R	C	C-A	C	C
IV. Bedding					
A. Cross beds	A	A	A	A-C	A-C
1. Ripples	C	C-A	A	A	A
2. Ripple drift	C-A	C	C-R	R-C	R-C
3. Festoon cross beds	A	A-C	C-A	C	C-A
4. Graded beds	R	R	C-A	R-C	R-C
5. Point bar accretion	A	C	R-N	R-N	R-N
6. Irregular bedding	A	C	R-C	R-C	R-C
V. Levee deposits	A	A-C	R-C	R	N
VI. Mineralogy of sandstones					
A. Lithic greywacke	A	A	A-C	R	R
B. Orthoquartzites	N	N	N-R	A-C	A
VII. Fossils					
A. Marine	N	R-C	C-A	A-C	A-C
B. Brackish	R	C	C	C-R	C-R
C. Fresh	C-R	R-C	R-N	N	N
D. Burrow structures	R	C	A	A	A

Key: A = abundant, C = common, R = rare, N = not present

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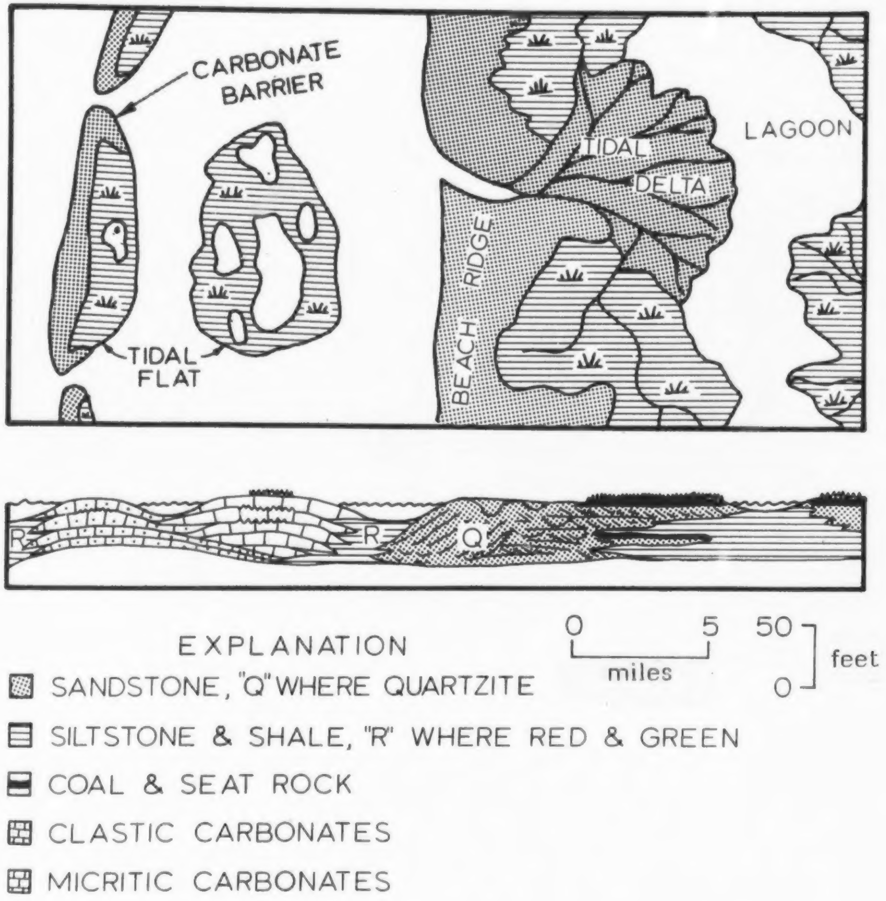
CARBONATE BARRIER
TIDAL FLAT
BEACH RIDGE
TIDAL DELTA
LAGOON
R
R
Q
EXPLANATION
0
5
miles
50
0
feet
▨ SANDSTONE, "Q" WHERE QUARTZITE
▤ SILTSTONE & SHALE, "R" WHERE RED & GREEN
▤ COAL & SEAT ROCK
▦ CLASTIC CARBONATES
▦ MICRITIC CARBONATES

Figure 30. Orthoquartzite beach barrier and lagoon, and carbonate tidal island and barrier environments (From Ferm and others, 1974).

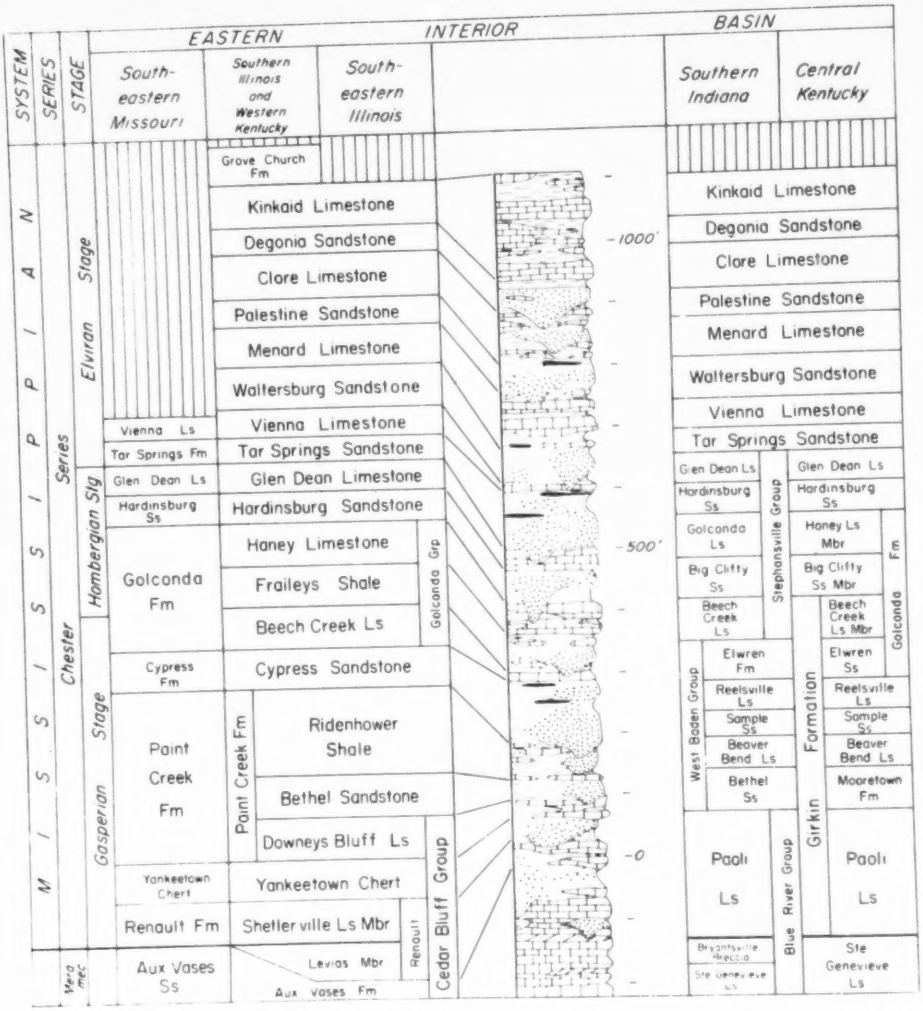
EASTERN INTERIOR BASIN
SYSTEM
SERIES
STAGE
South-eastern Missouri
Southern Illinois and Western Kentucky
South-eastern Illinois
Southern Indiana
Central Kentucky
MISSISSIPPIAN
Chester Series
Elviran Stage
Hombergian Stg
Gasperian Stage
Vero mec
Grove Church Fm
Kinkaid Limestone
Degonia Sandstone
Clore Limestone
Palestine Sandstone
Menard Limestone
Waltersburg Sandstone
Vienna Limestone
Tar Springs Sandstone
Glen Dean Limestone
Hardinsburg Sandstone
Haney Limestone
Fraileys Shale
Beech Creek Ls
Golconda Grp
Cypress Sandstone
Ridenhower Shale
Bethel Sandstone
Paint Creek Fm
Downeys Bluff Ls
Yankeetown Chert
Shetlerville Ls Mbr
Renault
Levias Mbr
Aux Vases Fm
Cedar Bluff Group
Vienna Ls
Tar Springs Fm
Glen Dean Ls
Hardinsburg Ss
Golconda Fm
Cypress Fm
Paint Creek Fm
Yankeetown Chert
Renault Fm
Aux Vases Ss
-1000'
-500'
-0
Glen Dean Ls
Hardinsburg Ss
Golconda Ls
Big Clifty Ss
Beech Creek Ls
Stephensville Group
Elwren Fm
Reelsville Ls
Sample Ss
Beaver Bend Ls
Bethel Ss
West Baden Group
Paoli Ls
Blue River Group
Bryantsville Breccia
Ste Genevieve Ls
Honey Ls Mbr
Big Clifty Ss Mbr
Beech Creek Ls Mbr
Golconda Fm
Elwren Ss
Reelsville Ls
Sample Ss
Beaver Bend Ls
Mooretown Fm
Girkin Formation
Paoli Ls
Ste Genevieve Ls

Figure 31. Graphic log of the Chester Series in the Eastern Interior showing frequent limestone and calcareous shale interbedded with coal (Pryor and Sable, 1974).

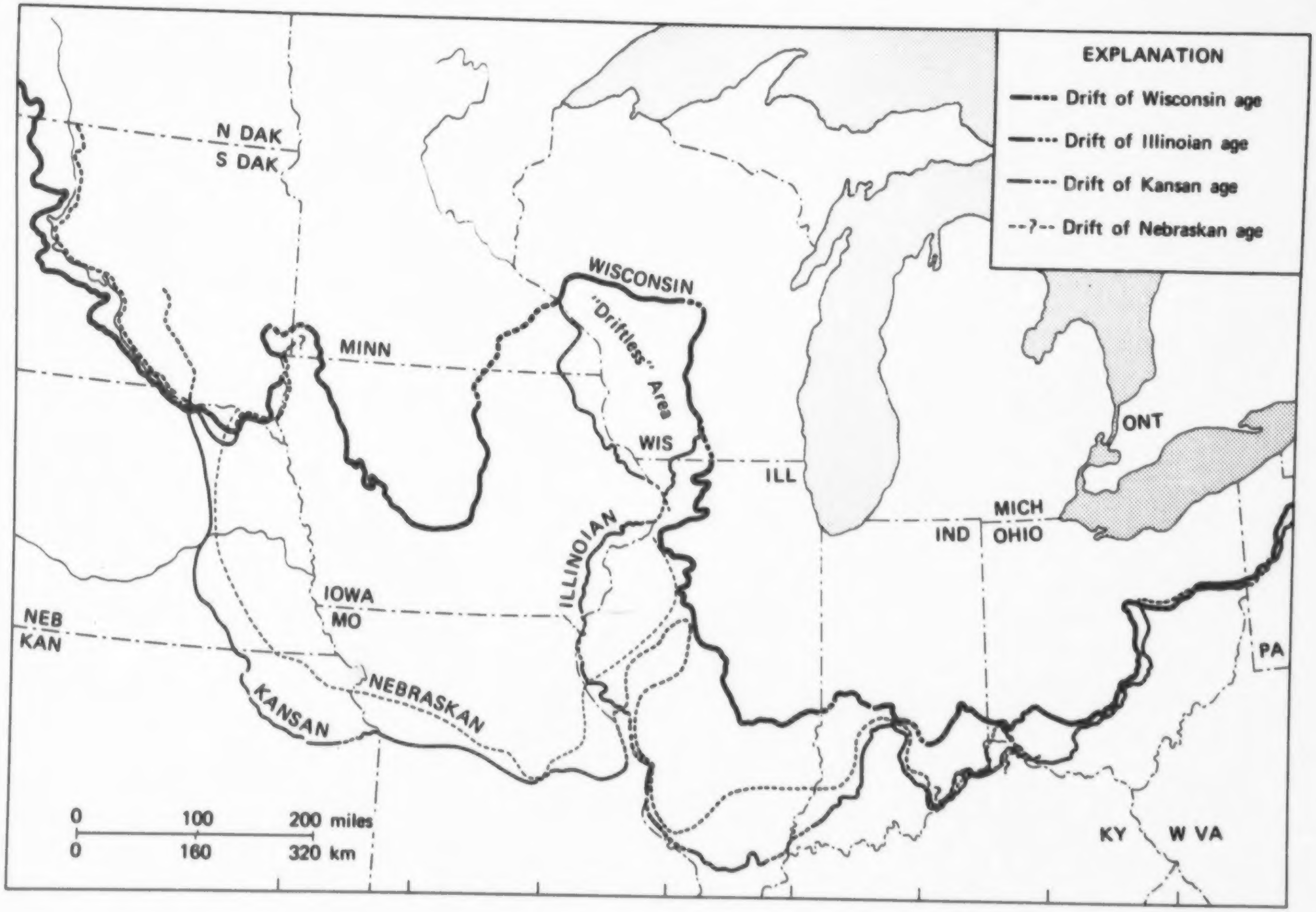
EXPLANATION
Drift of Wisconsin age
Drift of Illinoian age
Drift of Kansan age
--?-- Drift of Nebraskan age
N DAK
S DAK
MINN
WISCONSIN
"Driftless" Area
WIS
ILL
ONT
MICH
IND
OHIO
PA
IOWA
MO
NEB
KAN
ILLINOIAN
NEBRASKAN
KANSAN
KY
W VA
0
100
200 miles
0
160
320 km

Figure 32a. Known and inferred outer limits of four glacial stages in central North America. (From Richard F. Flint, Glacial and Quaternary Geology, 1971 Edition, Copyright John Wiley & Sons, Inc., NY, Reprinted by permission of John Wiley & Sons, Inc.)

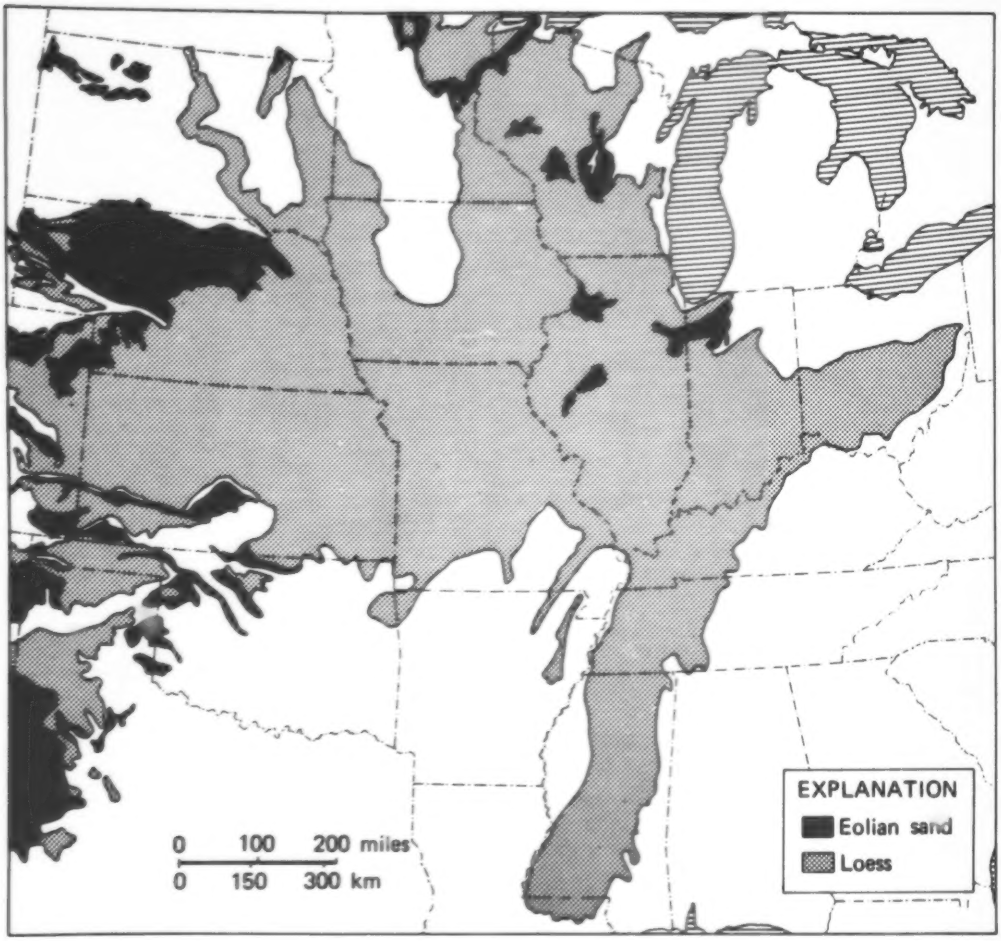
EXPLANATION
▇ Eolian sand
▨ Loess
0 100 200 miles
0 150 300 km

Figure 32b. Distribution of windblown sand and loess of Wisconsinan age in part of central North America. (Modified from Thorp, et al., 1952; by R. F. Flint, 1959)
(From Richard F. Flint, Glacial and Quaternary Geology, 1971 Edition, copyright, John Wiley and Sons, Inc., NY, Reprinted by permission of John Wiley and Sons, Inc., NY)

thinner than the depth of leaching, they lost their bicarbonate producing potential. Therefore, vast areas underlain by mineable coal contain older glacial drift (pre-Wisconsinan or early Wisconsinan) that is 1.5 to 12.2 m (or 5 to 40 ft) thick. Glacial drift may be placed above bedrock spoil deposits that presently lack neutralization potential, despite apparent similarity to adjacent drift deposits that are younger and less deeply weathered. Mine drainage will be different in quality for the two cases.

It should be apparent that, in addition to the acid potential of coal and overburden deposits, there are other valuable data bases that the planner must acquire. These bases include the geochemical characterization of groundwater and of overburden bedrock and unconsolidated overburden deposits*.

APPALACHIAN BASIN

Central Appalachian Region

Only a brief summary of the geology by mining region is appropriate here. The geology of coal-bearing strata is characterized by both lateral and vertical complexity that requires detailed mapping and correlation, at the local level, in order to establish the continuity of individual coal seams and associated strata. These details frequently may be obtained from state and federal geological publications. However, an overview will be presented so that the reader can appreciate the variability in geological setting.

Estimates (by region) of strippable coal reserves are of interest because these estimates give some indication where present and future mining activities are likely to be concentrated. It should be noted that estimates of strippable coal reserves are based on minimum coal bed thickness and maximum overburden thickness (Table 3). Table 3 also shows the economic stripping ratio, which is the ratio between overburden thickness and coal seam thickness. According to 1971 USBM figures, that ratio varies from state to state. In the future, as the value and scarcity of coal increases, this ratio might be expected to vary.

The central portion of the Appalachian Coal Region is the source of enormous amounts of bituminous coal and has been for more than 200 years. The states of Pennsylvania, West Virginia, Ohio, and a small portion of Virginia and Maryland are included in this region. Most of the area in this region lies within the Appalachian Plateau physiographic province. The Appalachian Plateau may be characterized as an extensively dissected plateau located in western Pennsylvania, much of West Virginia and Virginia. The terrain is less rugged westward, particularly in Ohio and extreme western Pennsylvania, where the glacial drift overburden tends to subdue the irregularities in the bedrock surface. The eastern edge of West Virginia and Maryland lie within the Appalachian Valley and Ridge Province, which is

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* In an engineering definition, any poorly cemented deposit of naturally occurring material that may be disaggregated by gentle mechanical means, such as stirring in water, is classified as a soil.

TABLE 3. CRITERIA FOR ESTIMATING STRIPPABLE RESERVES OF COAL AND LIGNITE (Source: USBM, 1971)

Province and state	Minimum coal bed thickness (inches)	Maximum overburden thickness for computing reserves (ft)	Economic stripping ratio (feet to feet)*
Eastern Province--Appalchian Region:			
Alabama	14	120	24:1
Kentucky--east	28	120	14:1
Maryland	28	120	15:1
Ohio	28	120	15:1
Pennsylvania	28	120	15:1
Tennessee	28	120	19:1
Virginia	28	120	15:1
West Virginia	28	120	15:1
Interior & Gulf Province:			
Arkansas (bituminous)	14	60	30:1
Arkansas (lignite)	30	100	30:1
Illinois	18	150	18:1
Indiana	14	90	20:1
Iowa	28	120	18:1
Kansas	12	120	15:1
Kentucky--west	24	150	18:1
Michigan	28	100	20:1
Missouri	12	120	15:1
Oklahoma	12	120	15:1
Texas	60	90	15:1
Rocky Mountain & Northern Great Plains Provinces:			
Arizona	60	130	8:1
Colorado	60	+50 to 120	4:1 to 10:1
Montana	60	+60 to 125	2:1 to 18:1
New Mexico	60	+60 and 90	8:1 to 12:1
North Dakota	60	+50 to 75	3:1 to 12:1
South Dakota	60	100	12:1
Utah	60	+39 to 150	3:1 to 8:1
Wyoming	60	+60 to 200	1.5:1 to 10:1
Pacific Coast Province:			
California	60	100	10:1
Oregon	48	40	4.75:1
Washington	60	100 and 250	10:1
Alaska	14	120	-

* Based on maximum feet of overburden thickness at the highwall per foot of coalbed thickenss.

+ Maximum overburden thickness varies for different coalbeds.

meters = feet x 0.3048 meters = inches x 0.0254 characterized by low northeast-southwest trending mountains formed of folded rocks. Local relief ranges from 91 to 152 m (300 to 500 ft) in eastern Ohio to 305 to 914 m (1000 to 3000 ft) in West Virginia.

Land use within these coal mining areas is either mostly forest, or cropland with pasture. Because of the sloping nature of much of the terrain, most surface mining in the central Appalachian coal region is some variation of the contour type method. Where the overburden thickness permits, mountaintop mining is also practiced. Area mining, however, is more prevalent in Ohio. Climates of these states are typical of the humid east with mean annual rainfall of 1016 to 1118 mm (40 to 44 in.) except in central West Virginia, where rainfall is 1219 to 1422 mm (48 to 56 in.) per year. A more detailed summary of climatic conditions is provided in Chapter 5.

A significant portion of coal production in the central Appalachians, particularly in recent years, is mined by strip methods. Strip mine production in 1973 was 27.2 million metric tons (30 million tons)(Pennsylvania), 15.4 million metric tons (17 million tons)(West Virginia), 26.3 million metric tons (29 million tons)(Ohio), 7.9 million metric tons (8.7 million tons)(Virginia), and 1.5 million metric tons (1.6 million tons)(Maryland). These numbers represent approximately 31% of the total coal production from strip mines in the United States.

The geographic locations of strip coal mined areas in 1973 are shown in Figure 33 (Keystone Coal Industry Manual, 1975, p. 39). Pennsylvania alone had 517 strip mines in 1967. Since a significant percentage of the original reserves of coal have been depleted, the USBM and other agencies, as well as the coal industry itself, maintains estimates (based on present mining technology) of remaining reserves. Results of a 1971 survey (USBM IC 8531) document the remaining strippable reserves of bituminous and subbituminous coal and lignite (Tables 4 and 5). It is interesting to note that at the 1973 rate of strip production, the remaining strippable reserves economically available with existing technology (1969) will last approximately as follows: Pennsylvania, 25 years; West Virginia, 124 years; Ohio, 37 years; Virginia, 28 years; and Maryland, 13 years.

Data on coal resources for the nation (Table 4) were assembled and evaluated to determine the quantity, location, and sulfur content of coal available by strip mining. Data on remaining strippable resources do not accurately indicate the amount of coal that can be mined economically, and are given in the tables mainly as a basis of comparison to other reports on strip coal resources.

Sulfur Content--

The amount of sulfur contained in the coals is critical to the utilization and value of the product. The general distribution of low-, medium-, and high-sulfur coals for the Central Appalachian Region is shown in Figure 34 (Keystone Coal Industry Manual, 1975, p. 37). Definition of these terms vary. Generally, low-sulfur coal is coal that contains less than 1% sulfur, by weight. Medium sulfur coal is either 1 to 2% or 1 to 3%, depending upon the author's definition. High-sulfur coal, then, can be coal with sulfur greater than 2% or 3%.

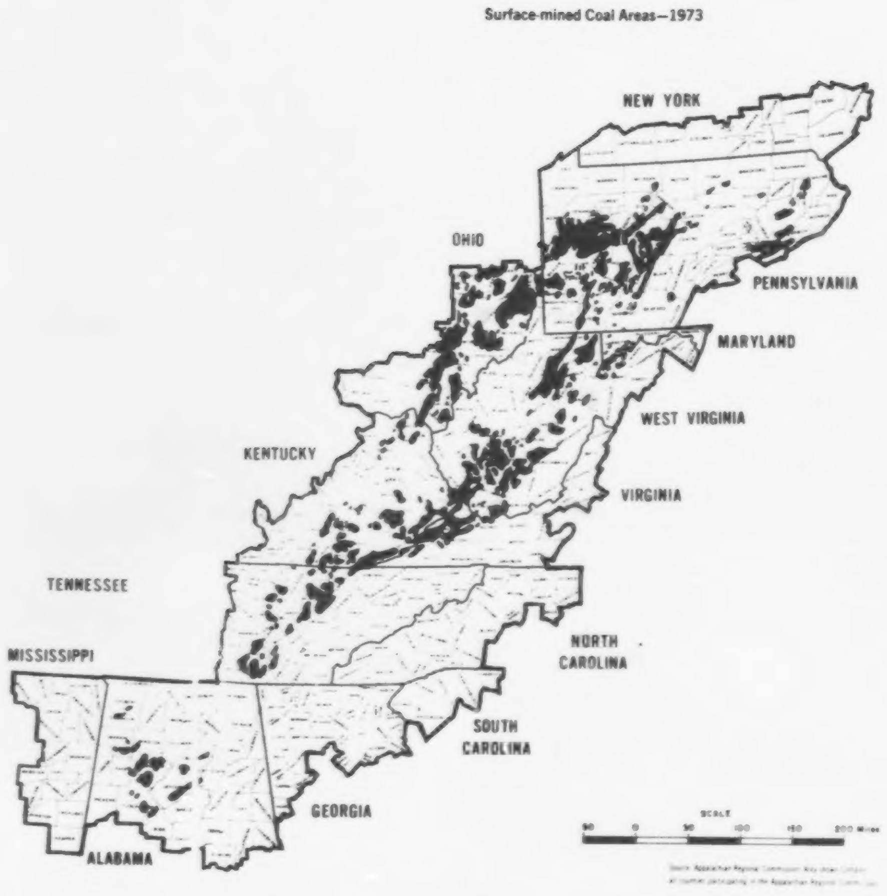

Surface-mined Coal Areas—1973
NEW YORK
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
VIRGINIA
TENNESSEE
NORTH CAROLINA
MISSISSIPPI
SOUTH CAROLINA
GEORGIA
ALABAMA
SCALE
50 0 50 100 150 200 Miles

Figure 33. Geographic locations of surface coal mined areas in 1973 (From 1975 Keystone Coal Industry Manual).

TABLE 4. REMAINING STRIPPABLE RESOURCES AND STRIPPABLE RESERVES OF COAL AND LIGNITE IN THE UNITED STATES, JANUARY 1, 1969 (Source USBM, 1971)

Rank	(Millions of short tons)				
			Strippable reserves		
	Remaining strippable resources	Strippable reserves	Low sulfur	Medium sulfur	High sulfur
BITUMINOUS COAL					
Eastern Province--Appalachian Region:					
Alabama	667	134	33	74	27
Kentucky--east	4,609	781	532	189	60
Maryland	150	21	0	8	13
Ohio	5,566	1,033	0	126	907
Pennsylvania	2,272	752	0	225	527
Tennessee	483	74	5	43	26
Virginia	1,556	258	154	99	5
West Virginia	11,230	2,118	1,138	669	311
Subtotal	26,533	5,171	1,862	1,433	1,876
Interior & Gulf Provinces:					
Arkansas	200	149	3	118	28
Illinois	18,845	3,247	0	80	3,167
Indiana	2,741	1,096	0	293	803
Iowa	1,000	180	0	0	180
Kansas	1,388	375	0	0	375
Kentucky--west	4,746	977	0	0	977
Michigan	6	1	0	0	1
Missouri	3,425	1,160	0	0	1,160
Oklahoma	434	111	10	44	57
Subtotal	32,785	7,296	13	535	6,748
Rocky Mountain & Northern Great Plains Provinces:					
Colorado	870	500	476	24	0
Utah	252	150	6	136	8
Subtotal	1,122	650	482	160	8
Alaska	1,201	480	480	0	0
Total Bituminous	62,826	13,597	2,837	2,128	8,632

(continued)

TABLE 4. (Continued)

Rank	Remaining strippable resources	Strippable reserves	Strippable reserves: Low sulfur	Strippable reserves: Medium sulfur	Strippable reserves: High sulfur
	(Millions of short tons)				
SUBBITUMINOUS					
Rocky Mountain & Northern Great Plains Provinces:					
Arizona	400	387	387	0	0
Montana	7,813	3,400	3,176	224	0
New Mexico	3,307	2,474	2,474	0	0
Wyoming	22,028	13,971	13,377	65	529
Subtotal	33,458	20,232	19,414	289	529
Pacific Coast Provinces:					
California	100	25	0	0	25
Oregon	0	0	0	0	0
Washington	500	135	135	0	0
Subtotal	600	160	135	0	25
Alaska	6,190	3,926	3,926	0	0
Total Subbituminous	40,338	24,318	23,475	289	554
LIGNITE					
Interior & Gulf Provinces:					
Arkansas	32	25	25	0	0
Texas	3,272	1,309	625	684	0
Subtotal	3,304	1,334	650	684	0

TABLE 5. ESTIMATED STRIPPABLE RESERVES OF COAL AND LIGNITE IN THE UNITED STATES, JANUARY 1, 1968 (Source: USBM, 1971)

State	Bituminous coal*	Subbituminous coal+	Lignite‡	Total
	(Millions of short tons)			
Alabama	134	0	(‡)	134
Alaska	§480	§#3,926	5	4,411
Arizona	0	387	0	387
Arkansas	149	0	25	174
California	0	25	0	25
Colorado	500	(+)	0	500
Illinois	3,247	0	0	3,247
Indiana	1,096	0	0	1,096
Iowa	180	0	0	180
Kansas	375	0	(‡)	375
Kentucky--east	781	0	0	781
Kentucky--west	977	0	0	977
Maryland	21	0	0	21
Michigan	1	0	0	1
Missouri	1,160	0	0	1,160
Montana	(*)	3,400	3,497	6,897
New Mexico	(*)	2,474	0	2,474
North Dakota	0	0	2,075	2,075
Ohio	1,033	0	0	1,033
Oklahoma	111	0	0	111
Pennsylvania	752	0	0	752
South Dakota	0	0	160	160
Tennessee	74	0	0	74
Texas	(*)	0	1,309	1,309
Utah	150	0	0	150
Virginia	258	0	0	258
Washington	(*)	135	0	135
West Virginia	2,118	0	0	2,118
Wyoming	(*)	13,971	0	13,971
Total	13,597	24,318	7,071	44,986

* Bituminous coal reserves not estimated for Idaho, Montana, Nebraska, New Mexico, Texas, Washington, and Wyoming.

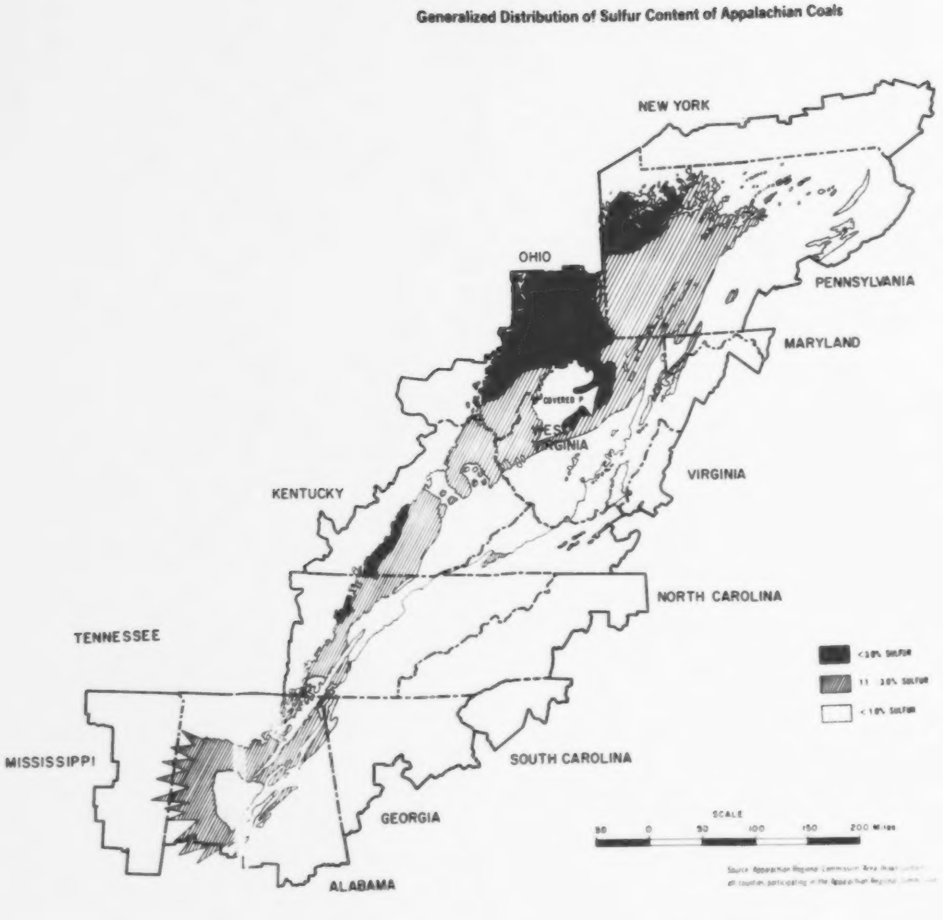
+ Subbituminous coal reserves not estimated for Colorado and Oregon.

‡ Lignite reserves not estimated for Alabama, Kansas, Louisiana, and Mississippi.

§ 478 million tons of bituminous and 3,387 million tons of subbituminous coal reserves in the northern Alaska fields (North Slope) are included in the estimates even though an economic export market, which is essential for exploitation, does not currently exist.

# Includes 179 million tons of undifferentiated subbituminous coal and lignite.

Note: An undetermined portion of the total strippable reserves are "captive" owned and are not available for sale in the open market. According to 1967 statistics of production by the 50 biggest bituminous underground and strip mines.


Generalized Distribution of Sulfur Content of Appalachian Coals
NEW YORK
OHIO
PENNSYLVANIA
MARYLAND
COVERED
WEST VIRGINIA
VIRGINIA
KENTUCKY
NORTH CAROLINA
TENNESSEE
MISSISSIPPI
SOUTH CAROLINA
GEORGIA
ALABAMA
<3.0% SULFUR
1.1 - 3.0% SULFUR
< 1.0% SULFUR
SCALE
50
0
50
100
150
200 Miles

Source: Appalachian Regional Commission Area [illegible]
all counties participating in the Appalachian Regional [illegible]

Figure 34. General distribution of low, medium, and high-sulfur coals in Central Appalachian Region (From 1975 Keystone Coal Industry Manual).

In any case, most low-sulfur coal in the central Appalachians is found in West Virginia and Virginia. West Virginia has an estimated 1.1 billion tons of low-sulfur coal, or about 4% of the nation's total reserves. Virginia has an estimated 154 million tons (USBM IC 8531, 1971). Most other low-sulfur coal, located in the Rocky Mountains and Northern Great Plains Provinces, is subbituminous coal.

Coal Seams--

Although coal seams are numerous throughout most Pennsylvanian-aged rocks, most coal production comes from a comparatively few, well developed seams that are already extensive. The depositional environment of Pennsylvanian-aged strata in the central Appalachians is predominantly nonmarine. The thickest part of the section is dominated by sandstone and conglomerate with intervening coal beds and associated clays and shale (Branson, 1962).

Cyclicity of beds (cyclothems) is common in the western portions of the basin. The strata are correlated throughout the area in a general way, with the coals and limestones most readily identifiable. The past and present terms for the major divisions of the Pennsylvanian System are given in Table 6 (Branson, 1962). The major coal-producing seams are found in the Pottsville, Allegheny, and Monongahela Groups. The principal coal beds of these groups, as correlated from state to state, are given in Table 7 (Branson, 1962).

Mining Districts--

Pennsylvania--Most strip-mined coal in Pennsylvania comes from the Main Bituminous Field in the western part of the state (Figures 35 and 36). Twenty seams have appreciable reserves of strippable coal. The coal-bearing strata are nearly horizontal but may be gently inclined up to 2.79 m per km (200 ft per mi) in the western coalfields and up to 75.8 m per km (400 ft per mi) farther east. Locally, as in the Broadtop Field, dip of strata may vary from 15 to 60 degrees or more from horizontal. Important strip-mined coals are the Upper Freeport, the Lower Freeport, and the Lower Kittanning (USBM IC 8531, 1971).

West Virginia--In West Virginia, strippable reserves are present in 40 counties in the state (Figure 37). Boone County leads with 15 percent, followed by Kanawha with 13 percent, Mingo with 8 percent, and Fayette and Logan Counties with 7 percent each. Important strip-mined coals are the Sewell, Eagle, Campbell Creek, No. 3 Pocahontas, Beckley, and others.

Ohio--Coal production in Ohio is primarily confined to the southeastern portion of the state, where rocks of the western edge of the Appalachian Basin are found (Figures 33 and 34). The rocks dip generally to the south and east at a rate of about 5.7 m per km (30 ft per mi). Over 75% of Ohio's 1974 production was from strip mines. Most of the production is from the Pittsburgh (No. 8) and Middle Kittanning (No. 6) seams. By seam, 31 percent of the strippable reserve is in the Middle Kittanning; 21 percent is in the Pittsburgh; 14 percent is in the Sewickley; and 12 percent is in the Upper Freeport (USBM IC 8531, 1971).

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TABLE 6. TERMINOLOGY OF TIME-STRATIGRAPHIC AND ROCK-STRATIGRAPHIC UNITS (Source: Branson, 1962)

Time-stratigraphic names	Rock-stratigraphic names
Dunkardian Series	Dunkard Group
Monongahelan Series	Monongahela Group
Conemaughan Series	Conemaugh Group
Alleghenian Series	Allegheny Group
Pottsvillian Series	Pottsville Supergroup

TABLE 7. PRINCIPAL COAL BEDS IN THE CENTRAL PORTION OF THE APPALACHIAN REGION (Source: Branson, 1962)

Ohio	W. Pennsylvania	West Virginia	Virginia	Anthracite district
	Jollytown			
Washington	Washington	Washington		
Waynesburg	Waynesburg	Waynesburg		
Uniontown	Uniontown	Uniontown		Salem
Meigs Creek	Sewickley	Sewickley		
Pomeroy	Redstone	Redstone		
Pittsburgh	Pittsburgh	Pittsburgh		Tunnel
Harlem	Elk Lick			Tracy
Anderson	Bakerstown	Bakerstown		Diamond
Mahoning	Mahoning	Mahoning		Primrose
				Holmes
U. Freeport	U. Freeport	U. Freeport		Mammoth
L. Freeport	L. Freeport	L. Freeport		
Kittanning	Kittanning	Kittanning		Skidmore
Brookville	Brookville	Brookville	Morris	Buck Mountain
		Winifrede	Pardee	
Tionesla				
Bedford				
U. Mercer	U. Mercer	Campbell Creek	Imboden	
L. Mercer	L. Mercer	Eagle	Eagle	
		Chilton	L. Banner	
		L. Douglas	Kennedy	
Quakertown		Castle	Jawbone	
Sharon	Sharon	Sewell	Seaboard	Lykens Valley
		Beckley	Beckley	
		Fire Creek	Fire Creek	
		Pocahontas	Pocahontas	
		Squire Jim		

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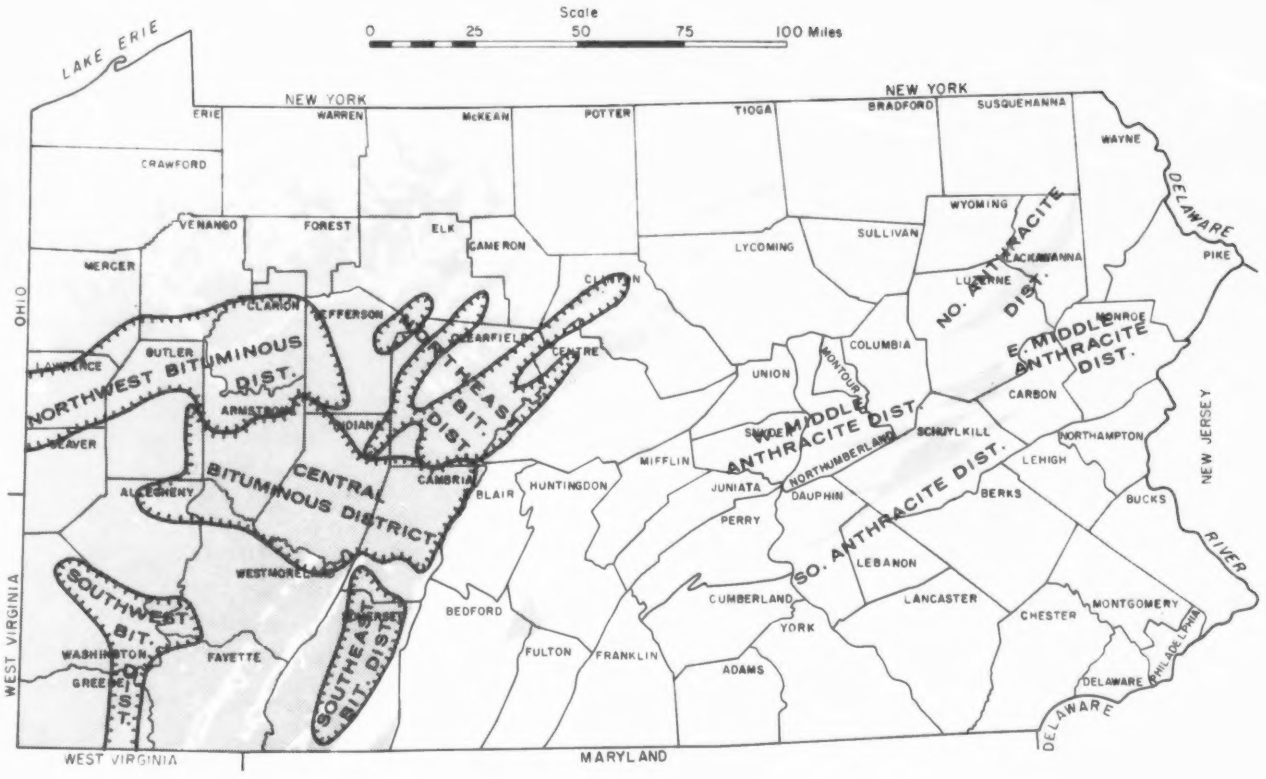
Scale
0
25
50
75
100 Miles
LAKE ERIE
NEW YORK
NEW YORK
OHIO
WEST VIRGINIA
WEST VIRGINIA
MARYLAND
NEW JERSEY
DELAWARE
DELAWARE
DELAWARE RIVER
ERIE
CRAWFORD
WARREN
McKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
PIKE
VENANGO
FOREST
ELK
CAMERON
MERCER
CLARION
JEFFERSON
CLEARFIELD
CLINTON
CENTRE
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
LUZERNE
MONROE
LAWRENCE
BUTLER
ARMSTRONG
INDIANA
CAMBRIA
BEAVER
ALLEGHENY
WESTMORELAND
WASHINGTON
GREENE
FAYETTE
SOMERSET
BEDFORD
BLAIR
HUNTINGDON
FULTON
FRANKLIN
MIFFLIN
JUNIATA
PERRY
CUMBERLAND
ADAMS
YORK
UNION
SNYDER
MONTOUR
COLUMBIA
NORTHUMBERLAND
SCHUYLKILL
DAUPHIN
LEBANON
LANCASTER
CARBON
NORTHAMPTON
LEHIGH
BERKS
BUCKS
MONTGOMERY
CHESTER
DELAWARE
PHILADELPHIA
NORTHWEST BITUMINOUS DIST.
CENTRAL BITUMINOUS DISTRICT
NORTHEAST BIT. DIST.
SOUTHWEST BIT. DIST.
SOUTHEAST BIT. DIST.
NO. ANTHRACITE DIST.
E. MIDDLE ANTHRACITE DIST.
W. MIDDLE ANTHRACITE DIST.
SO. ANTHRACITE DIST.

Figure 35. Principal areas of recent coal production in Pennsylvania (From Keystone Coal Industry Manual, 1975).

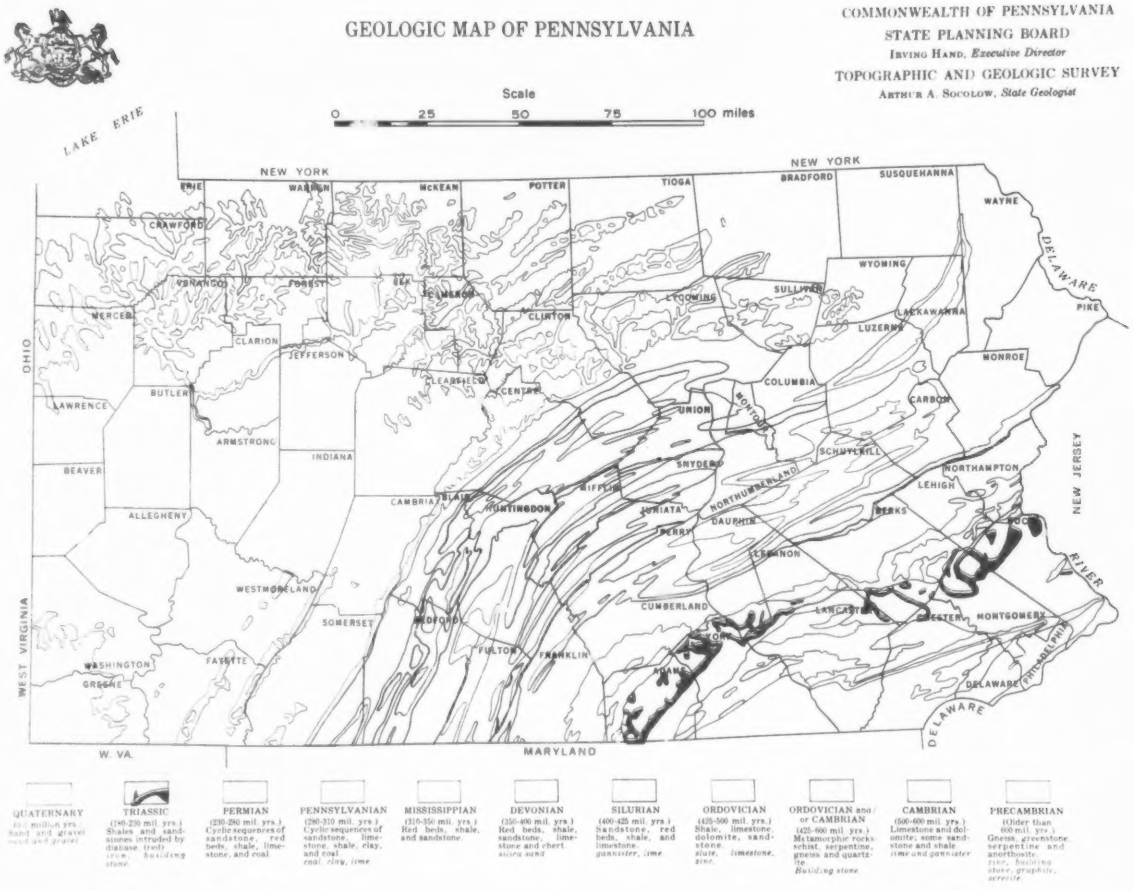
GEOLOGIC MAP OF PENNSYLVANIA
COMMONWEALTH OF PENNSYLVANIA
STATE PLANNING BOARD
IRVING HAND, Executive Director
TOPOGRAPHIC AND GEOLOGIC SURVEY
ARTHUR A. SOCOLOW, State Geologist
Scale
0 25 50 75 100 miles
LAKE ERIE
NEW YORK
OHIO
WEST VIRGINIA
W. VA.
MARYLAND
NEW JERSEY
DELAWARE
DELAWARE RIVER
ERIE
CRAWFORD
WARREN
MCKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
PIKE
MERCER
VENANGO
FOREST
ELK
CAMERON
CLINTON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
LUZERNE
MONROE
LAWRENCE
BUTLER
CLARION
JEFFERSON
CLEARFIELD
CENTRE
UNION
MONTOUR
COLUMBIA
CARBON
NORTHAMPTON
LEHIGH
BEAVER
ARMSTRONG
INDIANA
ALLEGHENY
CAMBRIA
BLAIR
HUNTINGDON
MIFFLIN
SNYDER
NORTHUMBERLAND
SCHUYLKILL
JUNIATA
PERRY
DAUPHIN
BERKS
LEBANON
WESTMORELAND
SOMERSET
BEDFORD
FULTON
FRANKLIN
CUMBERLAND
ADAMS
YORK
LANCASTER
CHESTER
MONTGOMERY
BUCKS
PHILADELPHIA
WASHINGTON
GREENE
FAYETTE
QUATERNARY (0-1 million yrs.) Sand and gravel sand and gravel
TRIASSIC (180-230 mil. yrs.) Shales and sandstones intruded by diabase (red) iron, building stone
PERMIAN (230-280 mil. yrs.) Cyclic sequences of sandstone, red beds, shale, limestone, and coal
PENNSYLVANIAN (280-310 mil. yrs.) Cyclic sequences of sandstone, limestone, shale, clay, and coal coal, clay, lime
MISSISSIPPIAN (310-350 mil. yrs.) Red beds, shale, and sandstone
DEVONIAN (350-400 mil. yrs.) Red beds, shale, sandstone, limestone and chert silica sand
SILURIAN (400-425 mil. yrs.) Sandstone, red beds, shale, and limestone gannister, lime
ORDOVICIAN (425-500 mil. yrs.) Shale, limestone, dolomite, sandstone slate, limestone, zinc
ORDOVICIAN and/or CAMBRIAN (425-600 mil. yrs.) Metamorphic rocks schist, serpentine, gneiss and quartzite Building stone
CAMBRIAN (500-600 mil. yrs.) Limestone and dolomite; some sandstone and shale lime and gannister
PRECAMBRIAN (Older than 600 mil. yrs.) Gneiss, greenstone, serpentine and anorthosite zinc, building stone, graphite, acrevite

Figure 36. Summary geological map of Pennsylvania showing the carboniferous strata of western Pennsylvania (From The Pennsylvania Geological Survey).

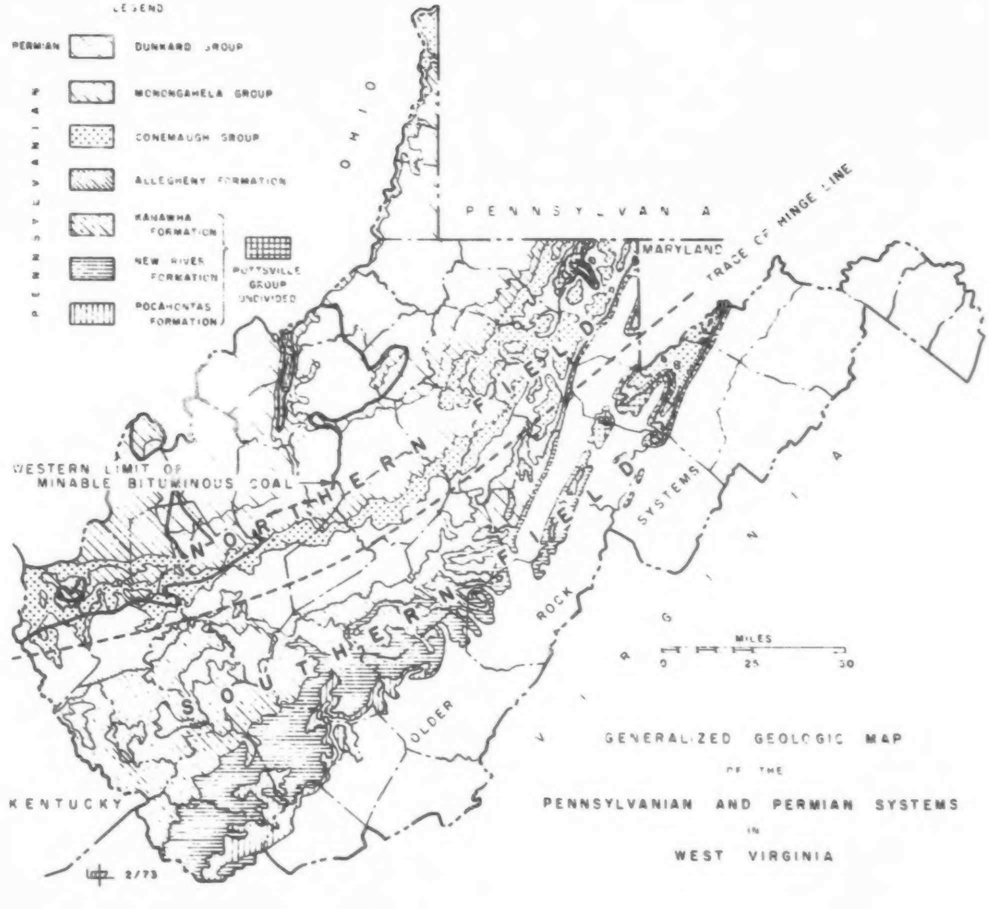
LEGEND
PERMIAN
DUNKARD GROUP
PENNSYLVANIAN
MONONGAHELA GROUP
CONEMAUGH GROUP
ALLEGHENY FORMATION
KANAWHA FORMATION
NEW RIVER FORMATION
POCAHONTAS FORMATION
POTTSVILLE GROUP UNDIVIDED
OHIO
PENNSYLVANIA
MARYLAND
TRACE OF HINGE LINE
WESTERN LIMIT OF MINABLE BITUMINOUS COAL
NORTHERN FIELD
SOUTHERN FIELD
OLDER ROCK SYSTEMS
VIRGINIA
KENTUCKY
MILES
0
25
50
GENERALIZED GEOLOGIC MAP
OF THE
PENNSYLVANIAN AND PERMIAN SYSTEMS
IN
WEST VIRGINIA
2/75

Figure 37. Generalized geologic map of the Pennsylvanian and Permian Systems in West Virginia (From 1975 Keystone Coal Industry Manual).

Virginia--Most coal production in Virginia comes from the southwest Virginia coalfields, which include the Pocahontas or Smokeless Field, the Virginia District Field, and the Buchanan Field (Figures 33, 34, and 38). Buchanan, Dickenson, Wise, and Russell counties account for most of the present production. In 1967, 11 percent of the state's production was from strip mines.

Maryland--Maryland's coal production comes from the northwest counties of Garrett and Allegany (Figures 33, 34, and 39). Coal of commercial importance is found in the Allegheny and Monongahela Groups. The most important coal producing area is the Cumberland Piedmont District. The coal beds in this basin are nearly flat near the axis, but dip as much as 15 degrees at the flanks. At the present time (1974), over 84 percent of Maryland's coal mining is by strip mining methods. The most important seams mined at present are the Pittsburgh, Sewickley, Barton, Franklin, Lower Bakerstown, and Freeport. Maryland has 19.1 million metric tons (21 million tons) of economically strippable coal reserve.

Sedimentation Models--

Geologists have proposed numerous models of sedimentation for the central Appalachian Basin. In these models an attempt has been made to describe paleoenvironments of deposition and erosion and the resulting stratigraphy. Models exist on a regional basis and, to a lesser degree, at the local level. The pattern and nature of sediments suggest that the northeast-southwest trending geosynclinal trough or basin, which existed in late Paleozoic time, was being filled primarily by clastic sediments that were derived from a nearby landform to the southeast (Figure 40). Coarse- to fine-grained clastic sediments encroached on swamp, lacustrine, and marine environments in northeast Kentucky, northern West Virginia, Maryland, Ohio, and Pennsylvania (Arkle, 1976). According to Donaldson (1974) paleoenvironments progressed from an extensive sea (Pottsville time), to a relatively small bay (Allegheny-lower Connemaugh time), to entirely river-influenced low-salinity bay-lake (upper Connemaugh-Monongahela time), to relatively small lakes of fluvial plain (Dunkard time) (Figure 40). The thickness and distribution of sediments suggest that sediments first filled the basin in the area centered in northern Virginia (Pocahontas Basin), and later the area centered in northern West Virginia (Dunkard Basin).

Pottsville Series--The stratigraphy of the Pottsville Series, as in most other series, is characterized by different formational names in each of the states where it is found (Table 8). The Pottsville Supergroup in West Virginia is divided into three groups. These are, in ascending order, the Pocahontas, the New River, and the Kanawha Groups. The Pocahontas, which occurs only in the axial belt of the Appalachian trough, is composed predominantly of sandstone, with many coal beds in the intervening shale units. The New River Group, which has the Pocahontas No. 8 (Lower Seaboard) at its base, attains a maximum thickness of approximately 244 m (800 ft). This group consists predominantly of sandstone, with thin shale units containing the coal beds. The Kanawha Group reaches a maximum thickness of about 305 m (1,000 ft) in West Virginia. These rocks are predominantly sandstone also. This group contains several marine limestones and thin, coal-bearing shales

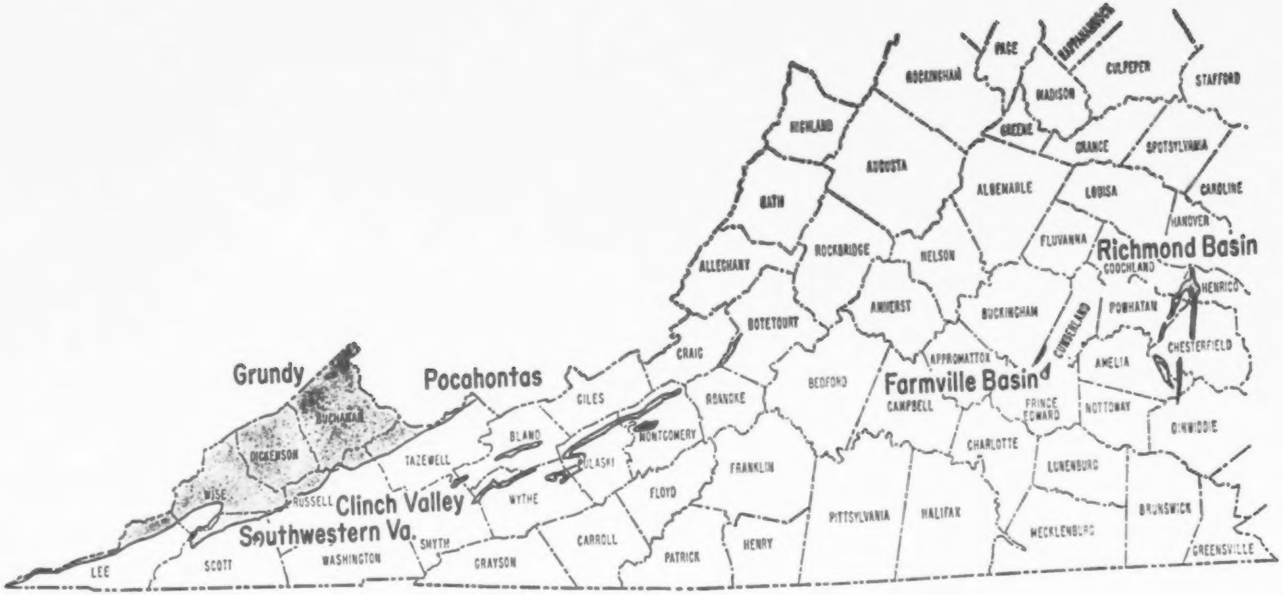
Grundy
Pocahontas
Clinch Valley
Southwestern Va.
Richmond Basin
Farmville Basin
LEE
SCOTT
WISE
DICKENSON
BUCHANAN
RUSSELL
WASHINGTON
TAZEWELL
SMYTH
GRAYSON
BLAND
WYTHE
GILES
PULASKI
CARROLL
MONTGOMERY
FLOYD
PATRICK
CRAIG
ROANOKE
FRANKLIN
HENRY
BOTETOURT
ALLEGHANY
BATH
HIGHLAND
ROCKBRIDGE
AUGUSTA
ROCKINGHAM
PAGE
RAPPAHANNOCK
MADISON
GREENE
CULPEPER
STAFFORD
ORANGE
SPOTSYLVANIA
ALBEMARLE
NELSON
AMHERST
BEDFORD
CAMPBELL
APPOMATTOX
BUCKINGHAM
FLUVANNA
LOUISA
CAROLINE
HANOVER
GOOCHLAND
HENRICO
POWHATAN
CUMBERLAND
CHESTERFIELD
AMELIA
PRINCE EDWARD
NOTTOWAY
DINWIDDIE
CHARLOTTE
LUNENBURG
PITTSYLVANIA
HALIFAX
MECKLENBURG
BRUNSWICK
GREENSVILLE

Figure 38. Distribution of coalfields of Virginia (From 1975 Keystone Coal Industry Manual).

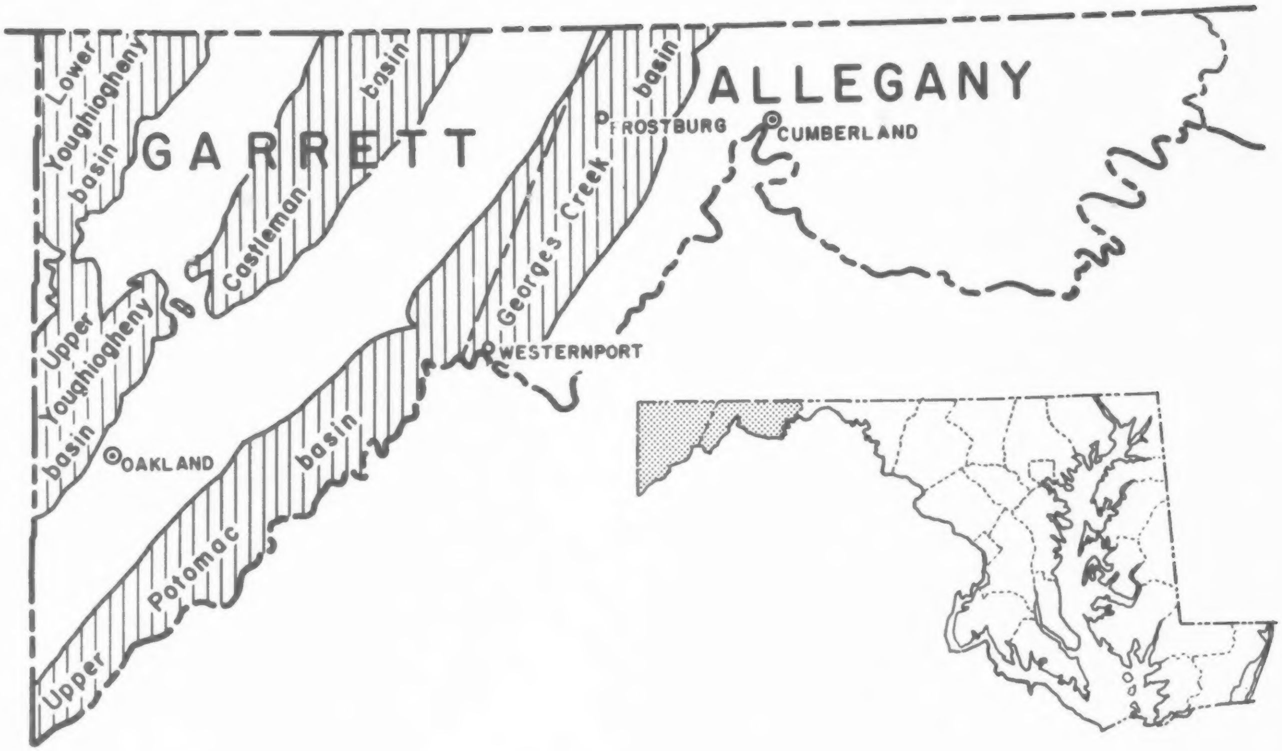
ALLEGANY
GARRETT
CUMBERLAND
FROSTBURG
WESTERNPORT
OAKLAND
Lower Youghiogheny basin
Castleman basin
Upper Youghiogheny basin
Georges Creek basin
Upper Potomac basin

Figure 39. Distribution of coalfields of Maryland (From 1975 Keystone Coal Industry Manual).

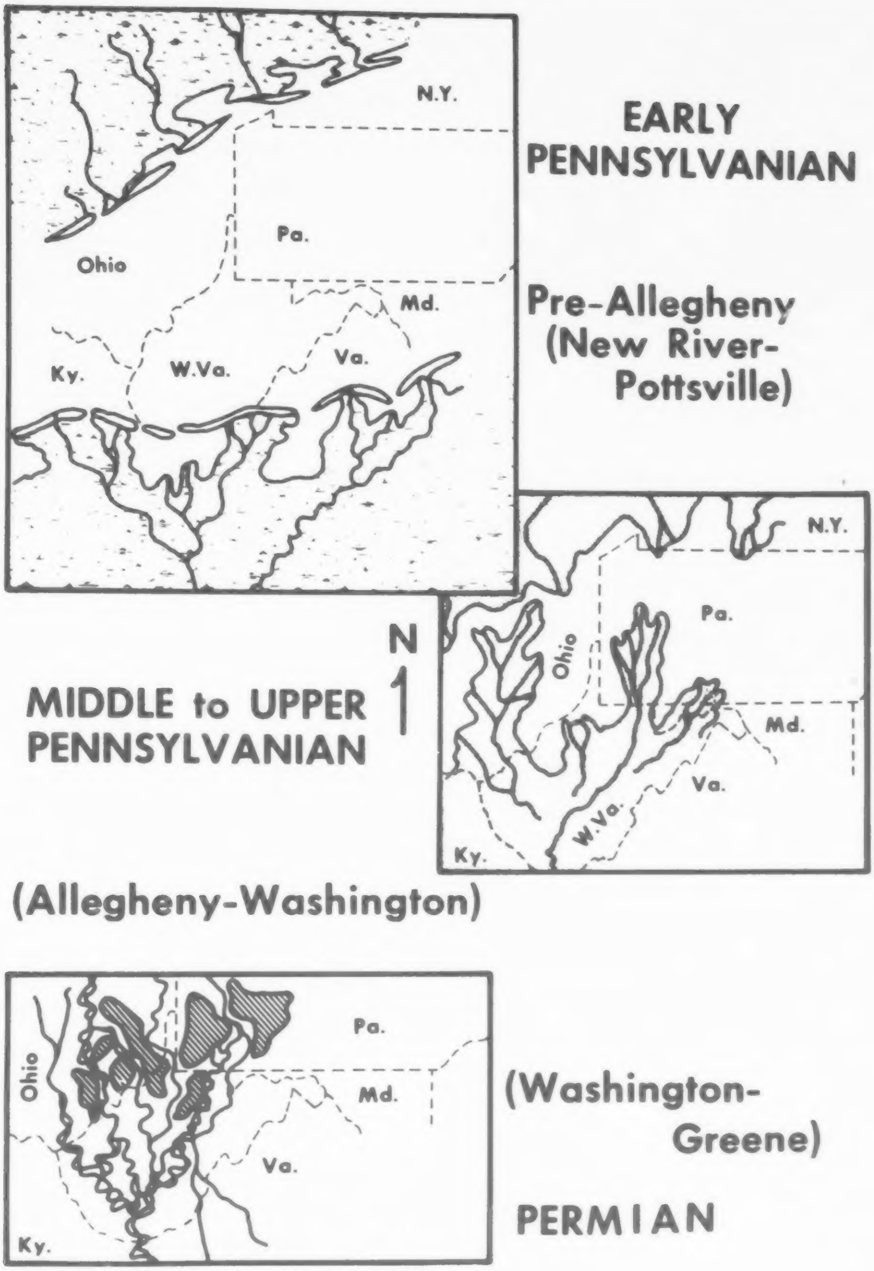
N.Y.
EARLY PENNSYLVANIAN
Pa.
Ohio
Md.
Pre-Allegheny (New River-Pottsville)
Ky.
W.Va.
Va.
N
MIDDLE to UPPER PENNSYLVANIAN
N.Y.
Pa.
Ohio
Md.
Va.
W.Va.
Ky.
(Allegheny-Washington)
Pa.
Ohio
Md.
Va.
Ky.
(Washington-Greene)
PERMIAN

Figure 40. Generalized paleographic maps for Pennsylvanian and Permian time. Pattern with diagonal lines for Permian paleographic map represents lakes (Donaldson, 1974).

TABLE 8. MAJOR DIVISIONS OF POTTSVILLIAN STRATA IN THE CENTRAL PORTION OF THE APPALCHIAN REGION (Source: Branson, 1962)

	Virginia	West Virginia	W. Pennsylvania	Anthracite District	Ohio
Pottsvillian	Wise Formation	Kanawha Group	Mercer Formation Connoquenessing Formation	Sharp Mt. Group	Tionesta Cyclothem Mercer members Quakertown member Connoquenessing member
	Gladeville ss.				
	Norton Formation	New River Group		Schuylkill Group	Sharon member Harrison Formation
	Lee Formation				
		Pocahontas Group		Tumbling Run Group	

also intervene. The distribution and thickness of the Pottsville strata, as it occurs in West Virginia and throughout the central Appalachians, is illustrated in Figure 41.

The Pottsville in Virginia is divided into the Lee, Norton, Gladeville, and Wise Formations (ascending order). The Lee Formation is composed of a basal conglomerate underlying shales with occasional prominent sandstones. There are ten coal beds in the Lee unit in Wise County, and twenty in Tazewell County, including the Pocahontas coals. The Lee Formation reaches a maximum thickness of 564 m (1,850 ft) in Virginia. The Norton Formation, which contains nine mineable coals, achieves a thickness of 427 m (1,400 ft). It is predominantly sandstone to the north, and predominantly shale to the south. Above this lies the Gladeville Sandstone, a locally conglomeratic sandstone. The Wise Formation, the top of the Pottsville, caps the section with a thickness of about 671 m (2,200 ft). This is a shale formation, with many sandstone beds and a very few marine limestones. Some twenty coal beds are found in the Wise Formation. Table 8 gives important coal found within Virginia and in the other central Appalachian states during the Pottsville, as well as in younger periods.

The Pottsville Group in Ohio represents only the highest part of the section and is only about 55 m (180 ft) thick. The units appear to be repetitious and have been classified into ten cyclothems, each with a coal bed.

Allegheny Series--The Allegheny Group contains several important coals, including the Freeport coals and the Kittanning seam (see Table 9). The group is typically defined as including strata from the bottom of the Clarion to the top of the Upper Freeport coal. Allegheny rocks are mostly sandy in West Virginia and somewhat more shaly in Pennsylvania and Ohio. In Ohio, marine shales and limestones are abundant. In Pennsylvania, the group is divided into three formations (in ascending order): the Clarion, Kittanning, and Freeport. In Ohio, the strata have been divided into 13 cyclothems, each with named members. The ideal normal cyclothem, in most cases incomplete, is as follows (modified from Branson, 1962):

Rock Unit	Water-Yielding Properties
marine shale or limestone	aquitard, thicker limestones can contain solution voids
coal	minor aquifer
underclay	aquitard
fresh-water limestone	aquitard except where thick and contains solution voids
sandstone and shale	coarser-grained, better sorted sandstone serves as an aquifer

The sandstones are not uniform in distribution or thickness, and in many places, rest in channels cut into older beds. The Allegheny Group is about 91 m (300 ft) thick in west-central Pennsylvania as well as in the Maryland coal basins. This group thins eastward to less than 31 m (100 ft) and westward to about 46 m (150 ft) in Ohio. The occurrence and thickness of the Allegheny, as well as its outcrop distribution, are given in Figure 42.

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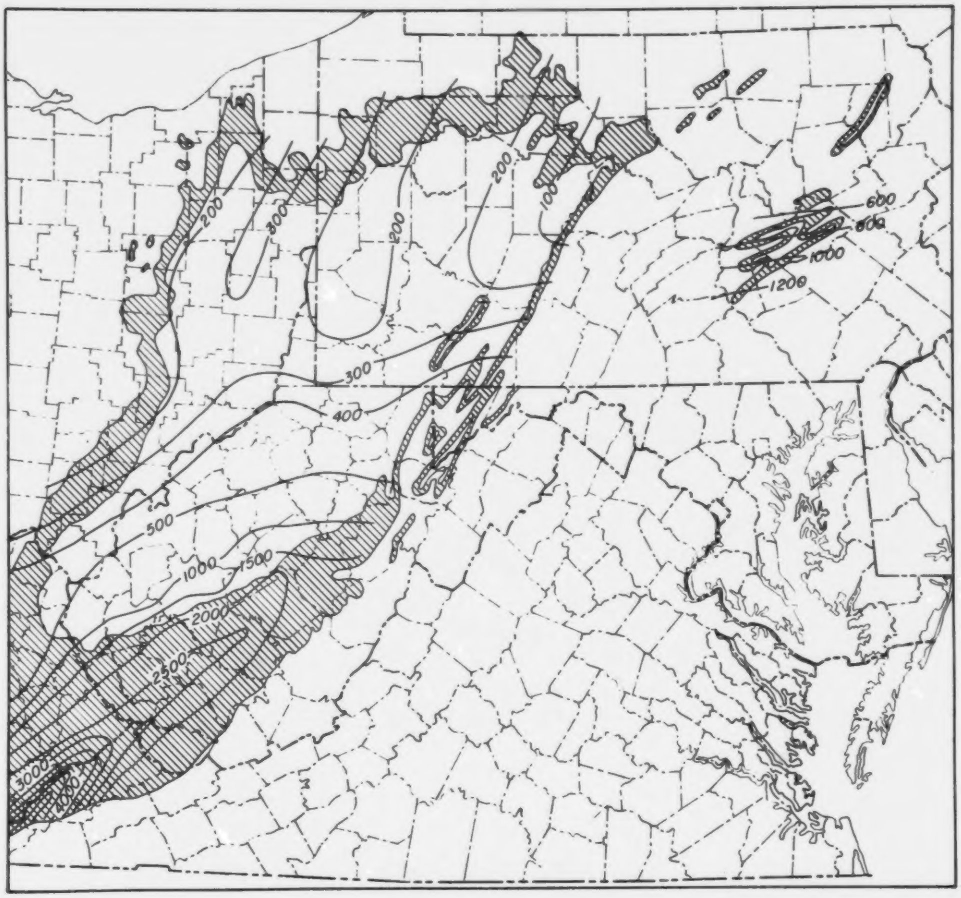
200
300
200
100
100
1200
200
300
400
500
1000
1500
2000
2500
3000
600
800
1000
1200

Figure 41. Distribution and isopachous map of the Pottsville Supergroup of the Central Appalachians. The cross-hatched region shows the outcrop region of the Pottsville Supergroup (Branson, 1962).

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TABLE 9. NOMENCLATURE FOR THE ALLEGHENY GROUP IN THE CENTRAL PORTION OF THE APPALACHIAN REGION (Source: Branson, 1962)

W. Pennsylvania		Ohio (Cyclothems)	West Virginia (Principal Named Units)
Freeport Formation		Upper Freeport	Upper Freeport Coal Upper Freeport Ls.
		Bolivar Lower Freeport	Bolivar Clay Lower Freeport Coal
	Upper Kittanning Sh. Nicely Run Member	Upper Kittanning	Upper Kittanning Coal Johnstown Ls.
Kittanning Formation	Middle Kittanning Complex Lower Kittanning Sh. Lower Kittanning Coal	Middle Kittanning Strasburg Lower Kittanning	Middle Kittanning Coal Lower Kittanning Coal
Clarion Formation		Lawrence Scrubgrass Clarion Winters Ogan Brookville	Clairon Coal

EPA-287 (Cin.)
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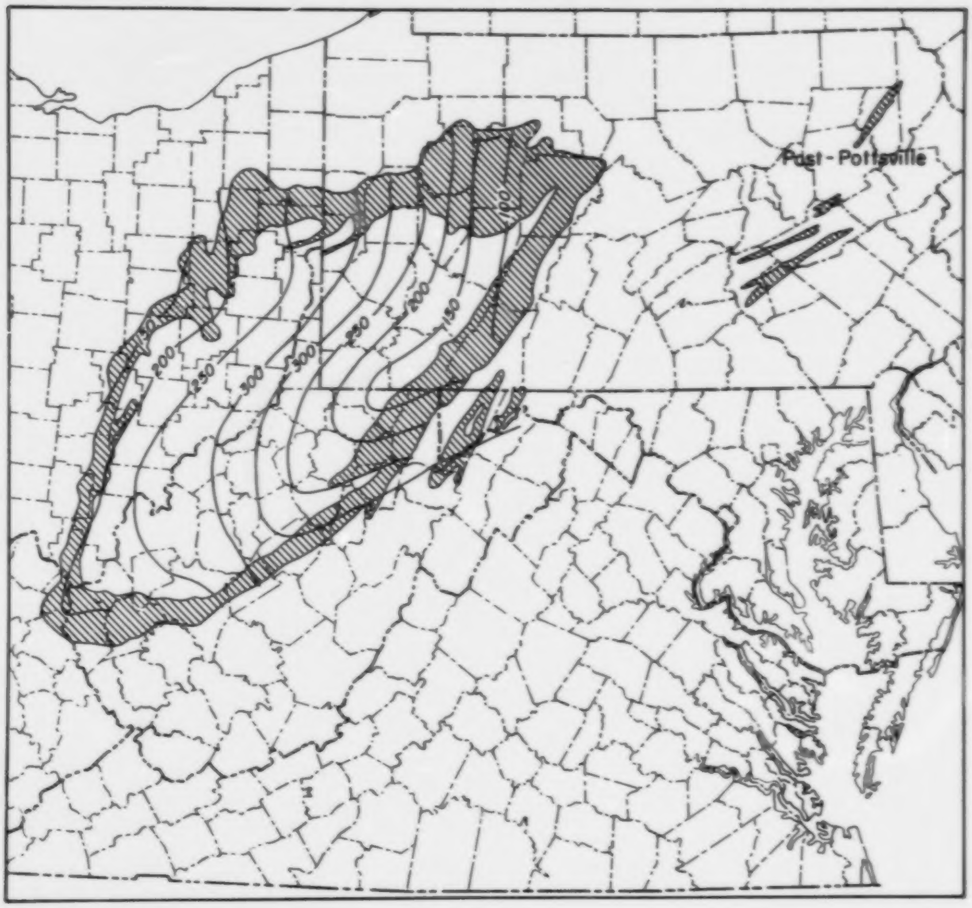
Post-Pottsville
100
150
200
250
300
300
250
200
150
100

Figure 42. Distribution and isopachous map of the Allegheny Group of the Central Appalachian Region. The cross-hatched region shows the outcrop region of the Allegheny Group (Branson, 1962).

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3/8"
PAGE NUMBER

Monongahela Series--The Monongahela Group lies above the Connemaugh Group, and most authors define the Monongahela Group to include strata from the base of the Pittsburgh coal to the top of the Waynesburg coal (Table 10). The thickness and distribution of these rocks, as shown in Figure 43, varies from approximately 152 m (500 ft) thick in West Virginia to less than 76 m (250 ft) thick in eastern Ohio. The rocks are approximately 76 m (250 ft) thick in Georges Creek Basin in Maryland. The group is predominantly shale and sandstone with some limestone in West Virginia, grading westward into a shale section in Ohio. Cyclothems are best developed and traceable over wide areas in Ohio and western portions of West Virginia and Pennsylvania. The ideal cyclothem of the Monongahela consists of (Branson, 1962):

Rock Unit	Water-Yielding Properties
roof shale	aquitard
coal	minor aquifer
underclay	aquitard to aquiclude
fresh-water limestone	minor aquifer where well developed and contains solution voids
red claystone	aquitard
mudstone	aquitard
sandstone	locally important aquifer

Occurrence of Limestone--

Pennsylvania--The Carboniferous limestones of Pennsylvania are most numerous in the southwestern portion of the state and become less abundant and, in general, of less economic importance northward and northeastward. A map showing limestone distribution is given in Figure 44 (Miller, 1934). The best and most abundant limestones are developed in the Allegheny, Monongahela and Washington Groups (Dunkard Series). The Vanport limestone of the Allegheny is the most valuable limestone of the Carboniferous strata of the state. Detailed descriptions of the occurrence and distribution of limestones throughout the coal-producing counties are available in several publications of the Pennsylvania Topographic and Geologic Survey.

Ohio--Pennsylvanian-aged limestones in eastern Ohio occur at twenty-seven different horizons that are widely spaced throughout the system (Lamborn, 1951). Limestones of marine origin are comparatively thin and confined to the lower half of the system. Fresh or brackish water limestones reach their best development in the upper half of the system, where they often consist of several layers of limestone separated by thin zones of calcareous shale.

Four limestone members occur in the Pottsville in Ohio, all of which are of marine origin and all of which are found closely overlying clay or coal beds. These limestones are generally thin but widely distributed. The Allegheny Series contains six limestone members. Three of these are of marine origin and occur closely overlying coal beds and three are of the fresh or brackish water type associated with coal measure clays.

Limestone beds at thirteen horizons have been recognized to outcrop in the Connemaugh Series. Five of the limestone members are marine and found

TABLE 10. PRINCIPAL NAMED UNITS FOR THE MONONGAHELA GROUP IN THE CENTRAL PORTION OF THE APPALACHIAN REGION (Source: Branson, 1962)

West Virginia (Named Units)	W. Pennsylvania (Named units)	Ohio (Cyclothems)
Waynesburg Coal	Waynesburg Coal	Waynesburg
Gilboy Ss.	Gilboy Ss.	
	Little Waynesburg Coal	Little Waynesburg
	Waynesburg Ls.	
Uniontown Ss.	Uniontown Ss.	
Uniontown Coal	Uniontown Coal	Uniontown
	Uniontown Ls.	L. Uniontown
Arnoldsburg Ss.	Arnoldsburg Ss.	
Arnoldsburg Coal		Arnoldsburg
	Fulton Green Shale	
Benwood Ls.	Benwood Ls.	Benwood
Sewickley Ss.	Sewickley Ss.	
Sewickley Coal	Sewickley Coal	Sewickley
L. Sewickley Ss.	Fishpot Ss.	L. Sewickley
Sewickley Ls.		Fishpot
	Fishpot Coal	
Redstone Coal	Redstone Coal	Redstone
Redstone Ls.	Redstone Ls.	
	U. Pittsburgh Coal	U. Pittsburgh
U. Pittsburgh Ss.		
Weston Sh.		Pittsburgh
Pittsburgh Coal	Pittsburgh Coal	

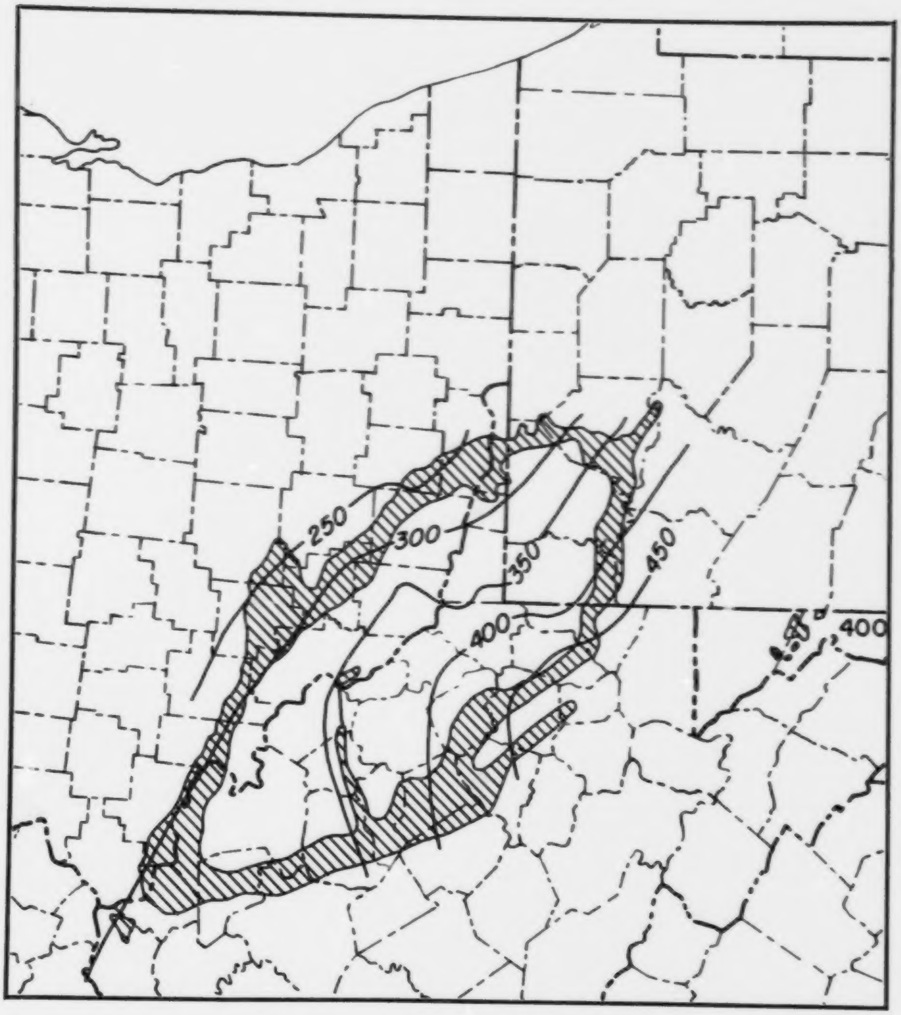
250
300
350
400
450
450
400

Figure 43. Distribution and isopachous map of the Monongahela Group of the Central Appalachian Region. Cross-hatched area shows region of outcrop (Branson, 1962).

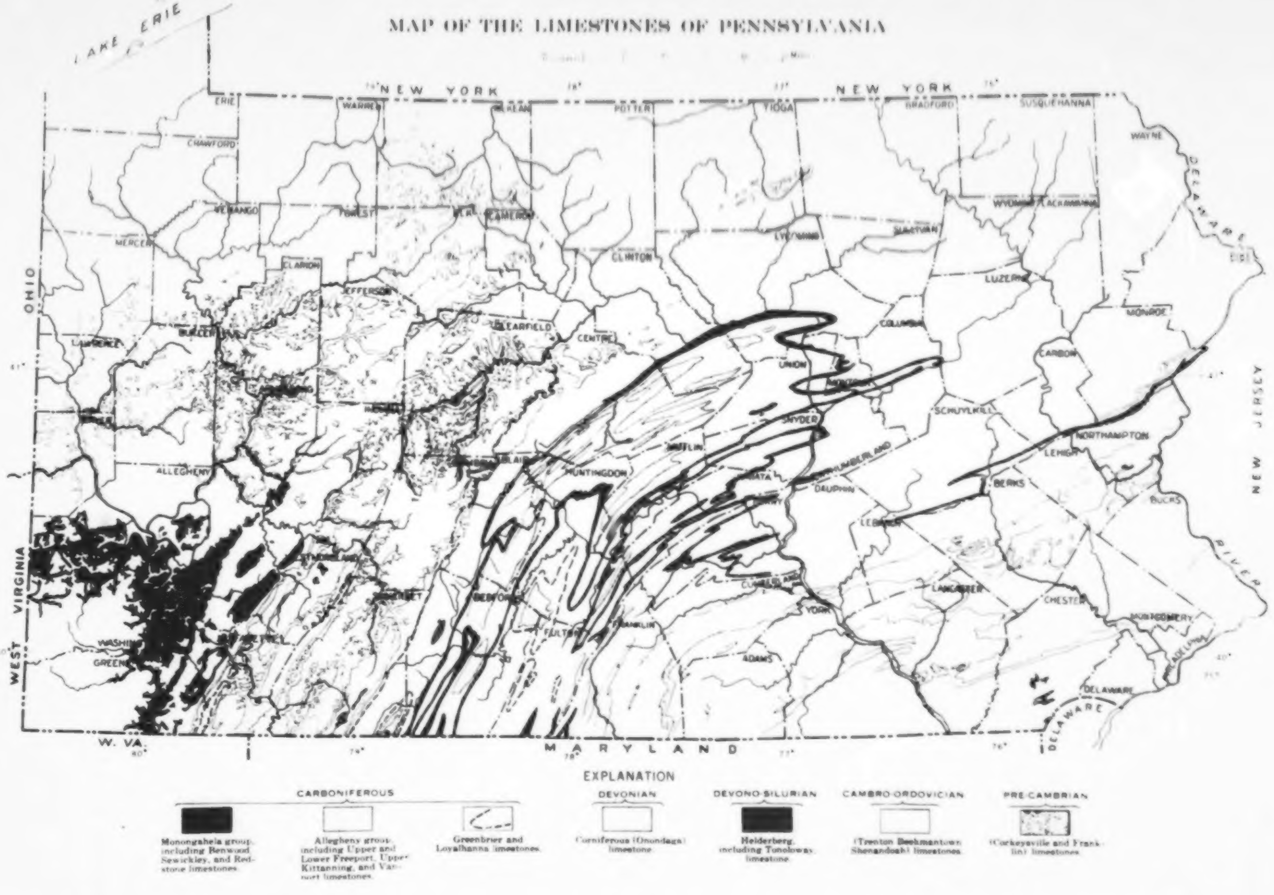
MAP OF THE LIMESTONES OF PENNSYLVANIA
LAKE ERIE
NEW YORK
NEW YORK
OHIO
WEST VIRGINIA
W. VA.
MARYLAND
NEW JERSEY
DELAWARE
DELAWARE RIVER
ERIE
CRAWFORD
WARREN
MCKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
VENANGO
FOREST
ELK
CAMERON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
MERCER
CLARION
JEFFERSON
CLINTON
LUZERNE
MONROE
LAWRENCE
BUTLER
CLEARFIELD
CENTRE
UNION
COLUMBIA
CARBON
SNYDER
MIFFLIN
SCHUYLKILL
NORTHAMPTON
LEHIGH
ALLEGHENY
HUNTINGDON
JUNIATA
NORTHUMBERLAND
DAUPHIN
BERKS
BUCKS
LEBANON
LANCASTER
CHESTER
MONTGOMERY
PHILADELPHIA
DELAWARE
WASHINGTON
GREENE
FAYETTE
SOMERSET
BEDFORD
FULTON
FRANKLIN
CUMBERLAND
ADAMS
YORK
80°
79°
78°
77°
76°
75°
EXPLANATION
CARBONIFEROUS
Monongahela group, including Benwood, Sewickley, and Redstone limestones
Allegheny group, including Upper and Lower Freeport, Upper Kittanning, and Vanport limestones
Greenbrier and Loyalhanna limestones
DEVONIAN
Corniferous (Onondaga) limestone
DEVONO-SILURIAN
Helderberg, including Tonoloway limestone
CAMBRO-ORDOVICIAN
(Trenton Beekmantown Shenandoah) limestones
PRE-CAMBRIAN
(Cockeysville and Franklin) limestones

Figure 44. Limestone distribution within the carboniferous of Pennsylvania (Miller, 1934).

closely overlying definite coal members. The rest are fresh or brackish water limestones that are associated with calcareous clays and argillaceous, calcareous shales found close below coal horizons. They tend to be less widely distributed than the marine limestones.

Limestone members of the Monongahela Series in Ohio are unusually well developed. They comprise, on the average, approximately 50 percent of the total thickness of the series (Lamborn, 1951). Six members are identified. Most or all are of fresh-water origin, usually interbedded with shale and frequently laterally graded into shale.

The Washington Series (Dunkard Group) of the Permian System contains five limestone members, all of the fresh-water type. They are widely distributed throughout the series but those having the most importance are confined stratigraphically to the upper part, and geographically to the northern part, of the belt of outcrops.

West Virginia--Pennsylvanian-aged rocks in West Virginia contain few and relatively unimportant limestones (economically), largely of fresh-water origin. Outcrops of limestone are scarcest in the central and southwest part of the state. In the Pottsville Series, very few limestones occur in the Pocahontas or New River Groups. Several thin, less than 1.5 m (4.9 ft), impure limestones are found in the Kanawha Group. Almost no limestones are found in the Pottsville in the northern part of the state where the section thins to about 91.4 m (300 ft).

Closely associated with the coals of the Allegheny Series are three relatively thin, variable, limy members, including the Vanport Limestone and the Upper and Lower Freeport Limestones. Within the Connemaugh Series, approximately a dozen limestone members have been described (McCue and others, 1939). They are mostly fresh-water, lenticular members of high variability in occurrence and purity.

The Monongahela Series contains five limestone members. Of these strata the Redstone Limestone, Sewickley Limestone, and Benwood-Uniontown Limestones are thickest and most extensive. These limestones, however, are restricted to the coal counties of northern West Virginia.

Eleven recognizable limestone units are found in the Dunkard Series. The only member that achieves significant thickness, however, is the lower Washington Limestone at 1.8 m (6 ft in Monongahela County, McCue and others, 1939). The rest rarely attain a thickness of more than a few meters anywhere.

Maryland--Limestones in Maryland are found associated with many of the important coals of the Allegheny and Monongahela Groups. In general, they are thin beds of fresh-water origin. The most important carboniferous limestone in the coal-bearing region is the Greenbrier Formation, which achieves a thickness of 19.8 m (65 ft) in places. Limestones in the coal-bearing rocks of Virginia are extremely scarce and for our purposes virtually nonexistent.

Southern Appalachian Region

The mining of coal in the southern regions of the Appalachian Basin is primarily confined to eastern Kentucky, Tennessee, and Alabama. (Virginia could also be included in this region, but for purposes of this report it is placed in the central Appalachians.) As in the coal-producing areas to the north, these states have a long tradition of coal mining. Surface mining of coal accounts for a significant portion of present production. The location of 1973 strip mine production is shown in Figure 33 (Keystone Coal Industry Manual, 1975).

Coal deposits for the most part lie just to the west of the Valley and Ridge Province, in the Appalachian Plateau Province. Kentucky and Tennessee coal regions lie in dissected plateaus that have a local relief of 152 to 610 m (500 to 2000 ft). Alabama's coalfields range from the flat coastal plains, across the plateau, and over to the western troughs of the Valley and Ridge Province.

Surface mine production of coal from the Southern Appalachian Region was 36.3 million metric tons (40 million tons) in 1973, 15 percent of the total U.S. strip mine production. In 1973, Alabama strip mined 10.7 million metric tons (11,8 million tons), Tennessee-3.7 million metric tons (4.1 million tons), and Kentucky-(eastern)-21.9 million metric tons (24.1 million tons). At present rates of mining, strippable reserves will be exhausted in 12 years (Alabama), 18 years (Tennessee), and 33 years (Kentucky). Strip-coal reserve estimates under less than 36.3 m (120 ft) of overburden are given in Table 5.

Sulfur Content--

Most coal in this region is of low- or medium- (1-3 percent) sulfur content. The general distribution of sulfur content in coal is given in Figure 34. Estimates of strippable reserves of low-sulfur coal are 482.6 million metric tons (532 million tons) in eastern Kentucky, 29.9 million metric tons (33 million tons) in western Kentucky, 29.9 million metric tons (33 million tons) in Alabama, and 4.5 million metric tons (5 million tons) in Tennessee. There are approximately 16 low-sulfur coal beds averaging 1.14 m (45 in.) thick in eastern Kentucky, three low-sulfur beds averaging 0.94 m (37 in.) thick in Tennessee, and 11 beds averaging 0.81 m (32 in.) thick in Alabama (USBM IC 8531, 1971).

Mining Districts--

Alabama--Coal deposits in Alabama are divided into four fields: the Coosa, Cahaba, Plateau, and Warrior (see Figure 45). A large number of coal seams are considered commercially important and are mined. The fields are located in structural basins, and each is partly bordered on the southeastern edge by a thrust fault. Generally, the dip of the strata is steep near the faults and fairly flat in the basins. Alabama coal beds are generally thin, and where thick, frequently carry thick rock partings.

Most of the present production comes from the Warrior Field. This is a basin-type structure covering approximately 9065 km (3,500 sq mi). The

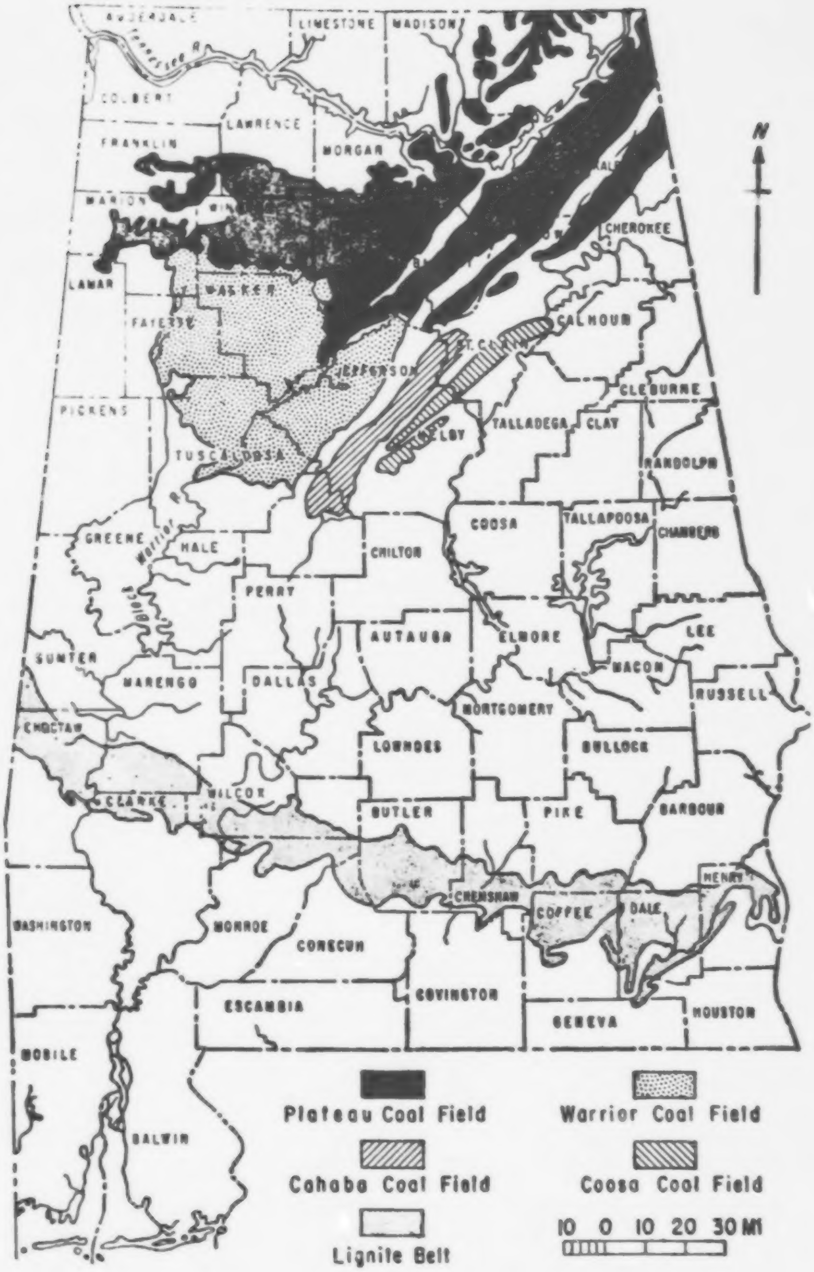
LAUDERDALE
LIMESTONE
MADISON
Tennessee R.
COLBERT
LAWRENCE
FRANKLIN
MORGAN
MARION
CHEROKEE
LAMAR
WALKER
FAYETTE
CALHOUN
ST. CLAIR
JEFFERSON
CLEBURNE
PICKENS
TALLADEGA
CLAY
SHELBY
TUSCALOOSA
RANDOLPH
Warrior R.
COOSA
TALLAPOOSA
CHAMBERS
GREENE
HALE
CHILTON
PERRY
AUTAUGA
ELMORE
LEE
SUMTER
MACON
MARENGO
DALLAS
RUSSELL
MONTGOMERY
CHOCTAW
LOWNDES
BULLOCK
CLARKE
WILCOX
BUTLER
PIKE
BARBOUR
HENRY
CRENSHAW
WASHINGTON
COFFEE
DALE
MONROE
CONECUH
ESCAMBIA
COVINGTON
GENEVA
HOUSTON
MOBILE
BALWIN
N
Plateau Coal Field
Warrior Coal Field
Cahaba Coal Field
Coosa Coal Field
Lignite Belt
10 0 10 20 30 MI

Figure 45. Distribution of coalfields of Alabama within the Southern Appalachian Region (Keystone Coal Industry Manual, 1975).

Plateau Field includes Sand and Blount Mountains, synclines separated from the rest of the field by erosion, as well as many other remnant mountains and knobs. Coal-forming rocks in the Cahaba coalfield are over 2,743 m (9,000 ft) thick and vary in dip, from horizontal to nearly vertical.

The coal beds are irregular in thickness and as a result of the folding and faulting, mining is difficult. Between 50 and 60 percent of the Alabama production is derived by surface mining. Counties and beds involved in strip mining include the following: Bibb--Wadsworth, Alice, Jones, Adkins, Coke, Thompson; Blount--Black Creek, Rosa; Cullman--Black Creek; Jackson--Underwood; Jefferson--Black Creek, Mary Lee, Newcastle, Gwin, Clements; Marion--Black Creek, Jefferson; Tuscaloosa--Clements, Johnson, Carter, Milldale, Brookwood; Walker--Black Creek, Jefferson, Mary Lee, Nickel Plate, Pratt; Winston--Black Creek, Jefferson.

Kentucky--Coal in Kentucky is found in two separate areas, the eastern coalfield of the Appalachian Region and the western coalfield of the Eastern Interior Basin (Figure 46). For purposes of this report, the Southern Appalachian Region encompasses only the eastern field. Topography among the coalfields is sufficiently variable to divide the area into three physiographic regions: the Cumberland Plateau, the Kanawha Plateau, and the Cumberland Mountains.

The Cumberland Plateau is a broad benchlike upland of relatively low relief. The Kanawha Plateau is a hilly or mountainous upland with narrow, crooked valleys where the divides are irregular, steep-sided ridges with sharp crests. The Cumberland Mountain section is similar to the Kanawha Plateau in the north, but in the south the rock dips more steeply and the topography is characterized by ridges and valleys (Huddle and others, 1963).

About 30 percent of the strip-mined coal production in the state comes from the eastern districts. Coal measures underlie approximately 26,599 sq km (10,270 sq mi) in 31 counties. The reserve districts are the Upper Cumberland River, Southwestern, Hazard, Big Sandy, Licking River, and Princess (Figure 46). Beds in these fields dip gently in an easterly or southeasterly direction. Seams with the largest strippable reserves are the Princess No. 3, Upper Elkhorn No. 3 (Jellico), Fire Clay, Hazard No. 7, and Princess No. 4 (USBM IC 8531, 1971).

Tennessee--The Tennessee coalfields lie in a belt 81 to 113 km (50 to 70 mi) wide, running southwesterly down the east-central part of the state (Figure 47).

Coal measures underlie approximately 12,950 sq km (5,000 sq mi) and mining operations exist in most of the twenty-two counties within this area. Many of the seams in northern Tennessee have been correlated with eastern Kentucky beds; seams in southern Tennessee have been correlated with beds in Alabama. On the basis of this seam relationship, the coalfields have been divided into the Northern and Southern fields. Most current production is from the Northern field.

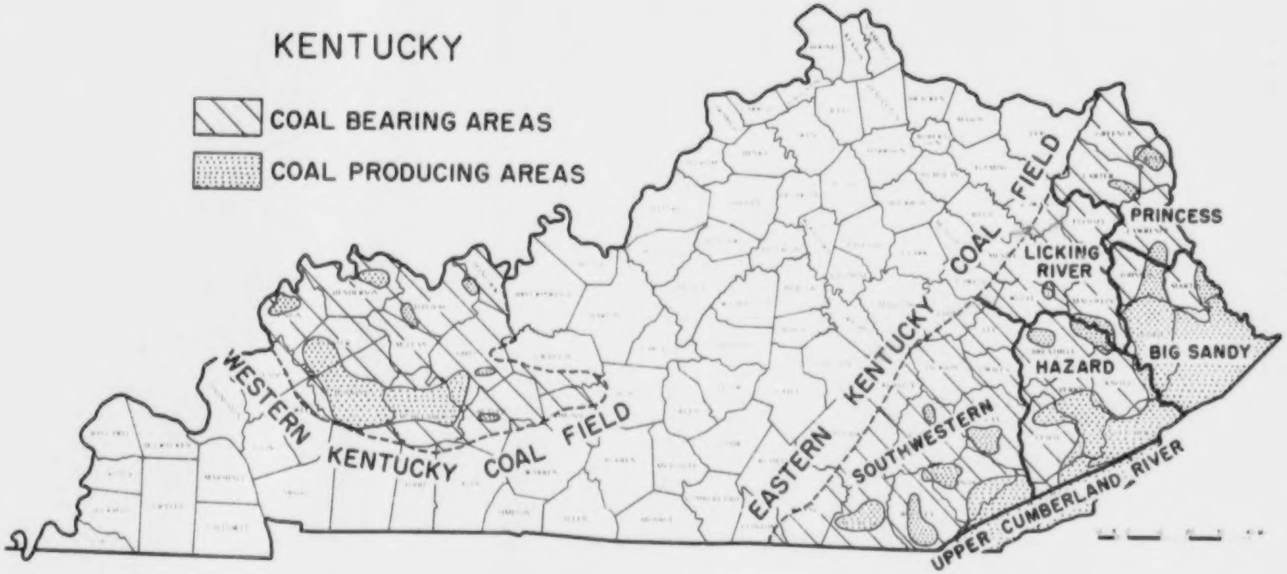
KENTUCKY
COAL BEARING AREAS
COAL PRODUCING AREAS
WESTERN KENTUCKY COAL FIELD
EASTERN KENTUCKY COAL FIELD
PRINCESS
LICKING RIVER
BIG SANDY
HAZARD
SOUTHWESTERN
UPPER CUMBERLAND RIVER

Figure 46. Distribution of coalfields of Kentucky within the Southern Appalachian Region (Keystone Coal Industry Manual, 1975).

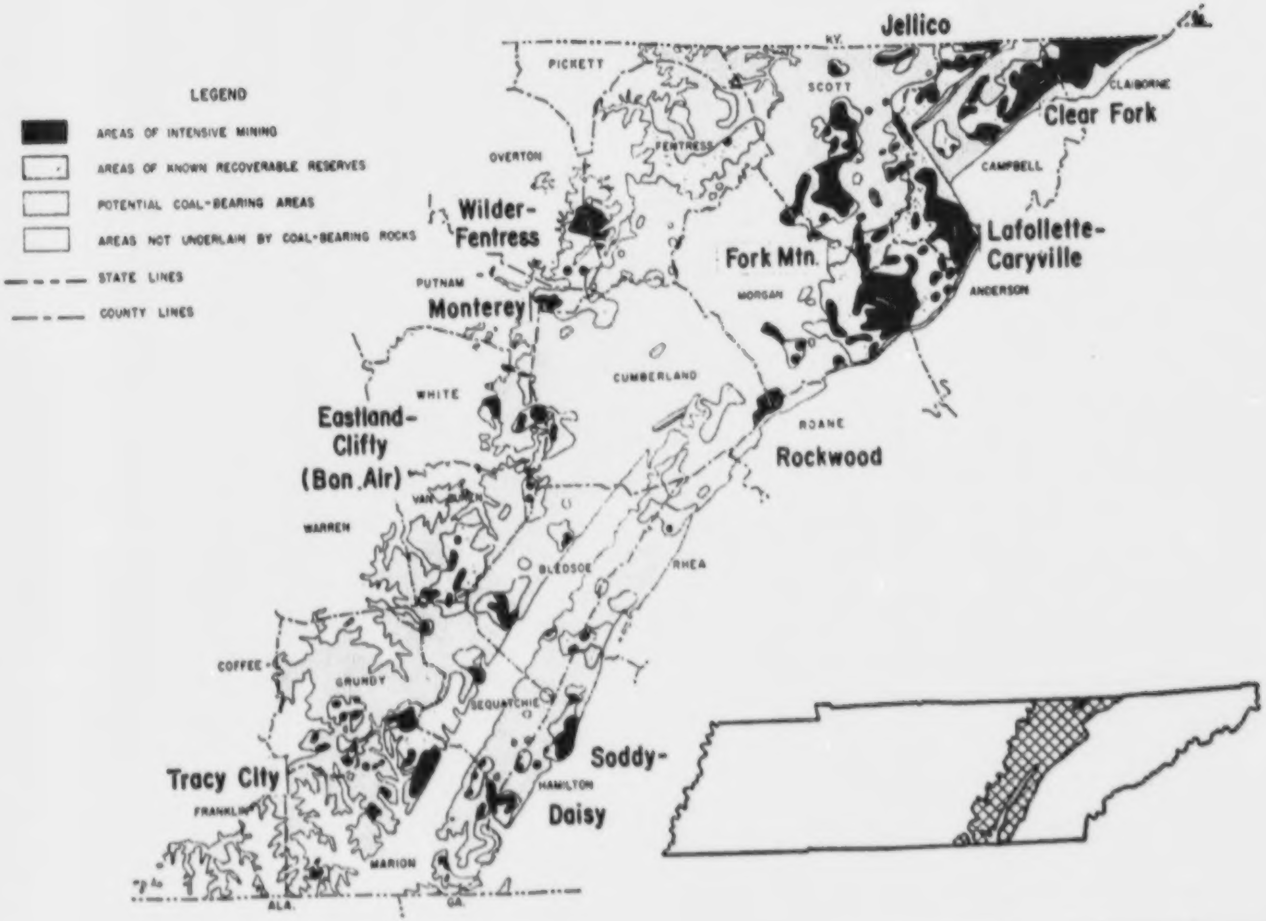
LEGEND
AREAS OF INTENSIVE MINING
AREAS OF KNOWN RECOVERABLE RESERVES
POTENTIAL COAL-BEARING AREAS
AREAS NOT UNDERLAIN BY COAL-BEARING ROCKS
STATE LINES
COUNTY LINES
KY.
Jellico
PICKETT
SCOTT
CLAIBORNE
Clear Fork
FENTRESS
CAMPBELL
OVERTON
Wilder-
Fentress
Lafollette-
Caryville
Fork Mtn.
MORGAN
ANDERSON
PUTNAM
Monterey
CUMBERLAND
WHITE
Eastland-
Clifty
(Bon Air)
ROANE
Rockwood
VAN BUREN
WARREN
BLEDSOE
RHEA
COFFEE
GRUNDY
SEQUATCHIE
Soddy-
Daisy
HAMILTON
Tracy City
FRANKLIN
MARION
ALA.
GA.

Figure 47. Distribution of coalfields of Tennessee within the Southern Appalachian Region (Keystone Coal Industry Manual, 1975).

Estimated strip-coal reserves are 67.1 million metric tons (74 million tons) of bituminous coal (Tables 4 and 5). Principal counties with strippable reserves are Campbell, Anderson, Morgan, Scott, and Van Buren. The largest reserves are found in Sewanee, Big Mary, Wilder, Jellico, and Poplar Creek seams.

Deposition Models--

The Southern Appalachian Coal Region is an extensive southwest-northeast section of Pennsylvanian rocks that are geologically continuous with the Appalachian Basin to the north. Physiographically, most coal deposits are located in the Cumberland Plateau (in Kentucky, Tennessee, and Virginia), and in the Warrior Plateau in Alabama (Figure 33). Like the Allegheny Plateau to the north, these provinces lie just west of the hilly folded Valley and Ridge Province.

These coalfields are erosional remnants of much thicker Pennsylvania sediments which probably once covered the eastern United States. The northern section of this region (Kentucky) is part of the Pocahontas Basin while Alabama and Mississippi lie in the Warrior Basin. Tennessee is underlain by a thinner section of sediments which connect the Pocahontas Basin and the Warrior Basin.

Beds younger than the oldest division of the Pennsylvania (the Pottsville) are found only in northern Tennessee, Kentucky, and Virginia. Even in these areas, the strata are of limited extent and of little regional significance. The Pottsville reaches its greatest thickness (2438 to 3048 m, which is 8,000 to 10,000 ft) in Alabama. It is divided into three groups: Pocahontas (oldest), New River, and Kanawha. Sandstones and shales predominate, while limestones are thin, highly irregular, and commonly discontinuous in a single outcrop (Metzger, 1965). The Pocahontas is limited in distribution to parts of Virginia, Alabama, and Mississippi. The correlation of the coals and important rock strata from Alabama to Virginia are given in Figures 48 and 49 (Strearns and Mitchum, 1962).

Pennsylvania sediments in the southern Appalachian coalfield consist of shale, sandstone, siltstone, conglomerate, underclay, coal, ironstone, and limestone, in about that order of abundance (Wanless, 1946). Shales vary from sand to clay and are generally gray to black. The truly marine zones are mostly shales, and in some instances, associated with a thin band of impure limestone or with limestone concretions.

Sandstones are generally clean, micaceous, and at places carbonaceous. Coals show considerable variation in thickness and many of them split. They characteristically occur in zones containing several seams, which are separated by partings of various materials.

In Tennessee, the basal Pennsylvania beds along the western edge of the Plateau rest disconformably on limestones and limy shales of older rocks of the Mississippi system. Within the Pennsylvanian-aged strata, there are only very thin and sporadic limestones.

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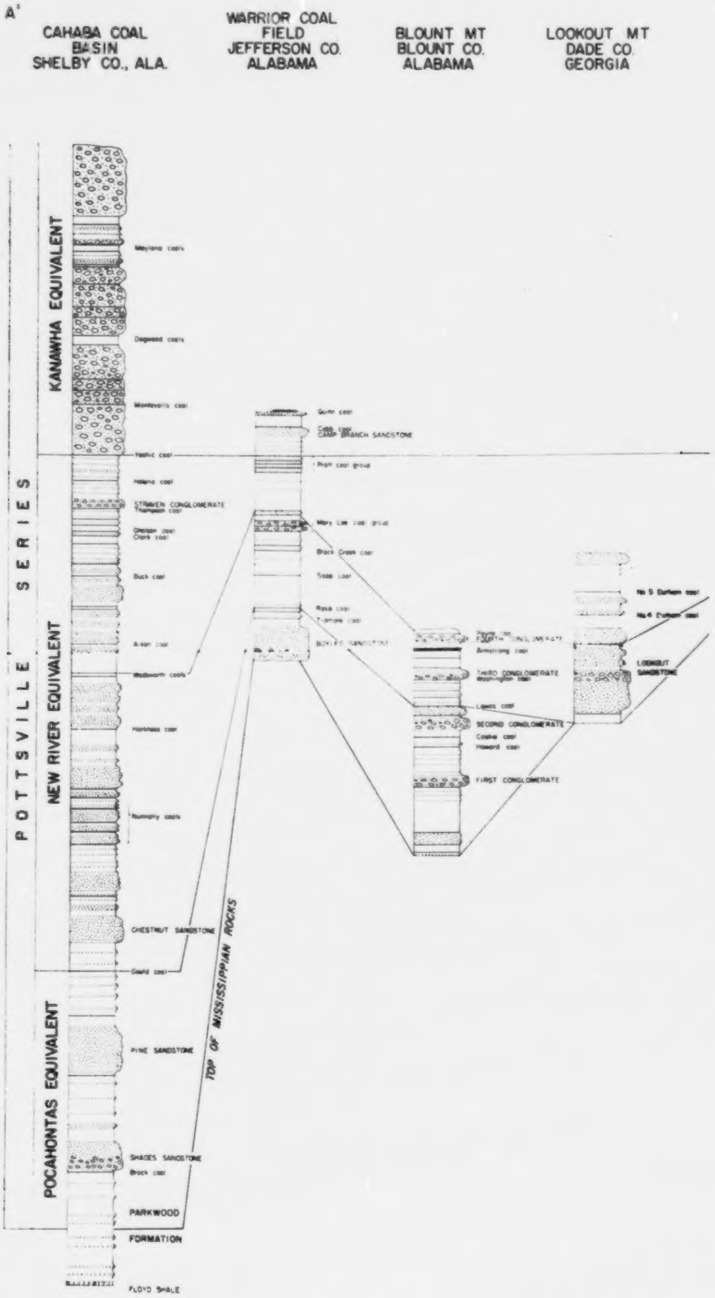
A'
CAHABA COAL BASIN SHELBY CO., ALA.
WARRIOR COAL FIELD JEFFERSON CO. ALABAMA
BLOUNT MT BLOUNT CO. ALABAMA
LOOKOUT MT DADE CO. GEORGIA
POTTSVILLE SERIES
KANAWHA EQUIVALENT
NEW RIVER EQUIVALENT
POCAHONTAS EQUIVALENT
Maylene coals
Dogwood coals
Montevallo coal
Yeshic coal
Helena coal
STRAVEN CONGLOMERATE
Thompson coal
Gholson coal
Clark coal
Buck coal
Akron coal
Wadsworth coals
Harkness coal
Nunnally coals
CHESTNUT SANDSTONE
Gould coal
PINE SANDSTONE
SHADES SANDSTONE
Brock coal
PARKWOOD
FORMATION
FLOYD SHALE
TOP OF MISSISSIPPIAN ROCKS
Gwin coal
Cobb coal
CAMP BRANCH SANDSTONE
Pratt coal group
Mary Lee coal group
Black Creek coal
Soda coal
Rosa coal
Tidmore coal
BOYLES SANDSTONE
Payne coal
FOURTH CONGLOMERATE
Armstrong coal
THIRD CONGLOMERATE
Washington coal
Lewis coal
SECOND CONGLOMERATE
Cooke coal
Howard coal
FIRST CONGLOMERATE
No 5 Durham coal
No 4 Durham coal
LOOKOUT SANDSTONE

Figure 48. Stratigraphic correlation of coals and important rock strata from Shelby County, Alabama to Wise County, Virginia (Strearns and Mitchem, 1962).

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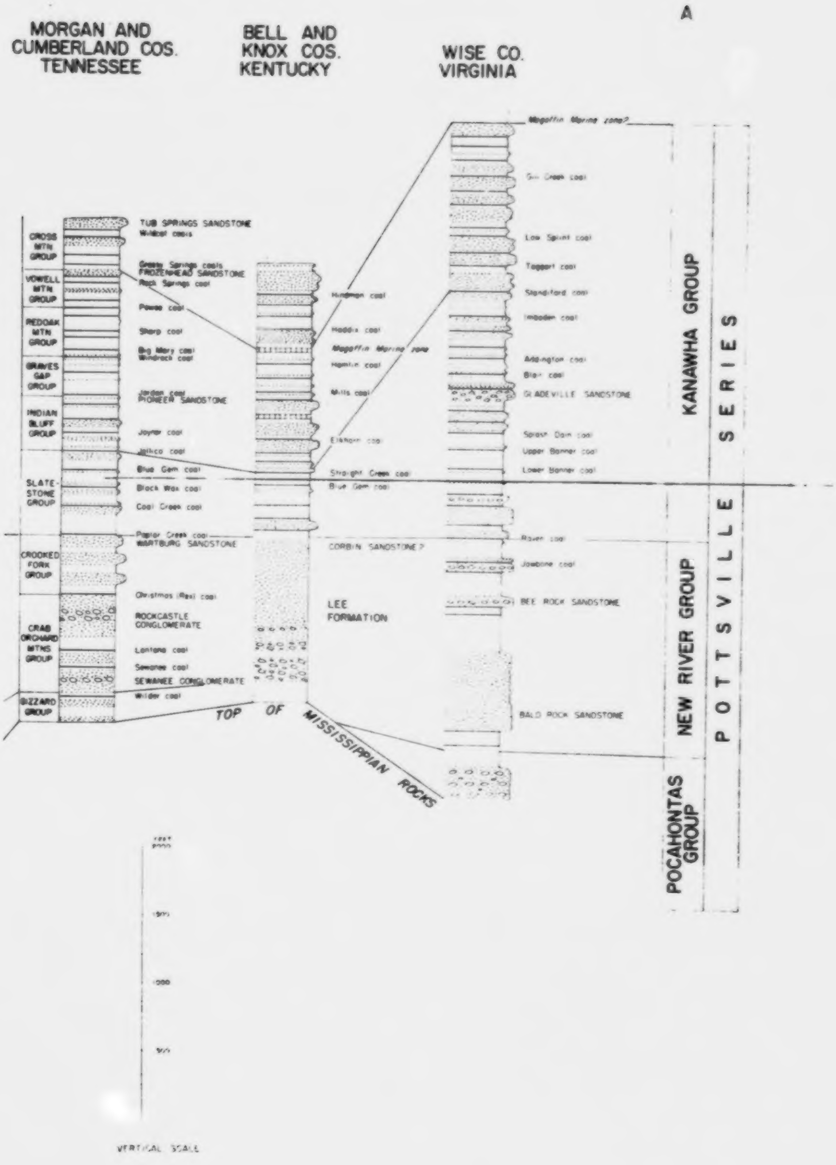
A
MORGAN AND CUMBERLAND COS. TENNESSEE
BELL AND KNOX COS. KENTUCKY
WISE CO. VIRGINIA
CROSS MTN GROUP
VOWELL MTN GROUP
REDOAK MTN GROUP
GRAVES GAP GROUP
INDIAN BLUFF GROUP
SLATE-STONE GROUP
CROOKED FORK GROUP
CRAB ORCHARD MTNS GROUP
BIZZARD GROUP
TUB SPRINGS SANDSTONE
Wildcat coals
Green Springs coals
FROZENHEAD SANDSTONE
Rock Springs coal
Pewee coal
Sharp coal
Big Mary coal
Windrock coal
Jordan coal
PIONEER SANDSTONE
Joyner coal
Jellico coal
Blue Gem coal
Black Wax coal
Coal Creek coal
Poplar Creek coal
WARTBURG SANDSTONE
Christmas (Rex) coal
ROCKCASTLE CONGLOMERATE
Lantana coal
Sewanee coal
SEWANEE CONGLOMERATE
Wilder coal
Hindman coal
Haddix coal
Magoffin Marine zone
Hamlin coal
Mills coal
Elkhorn coal
Straight Creek coal
Blue Gem coal
CORBIN SANDSTONE?
LEE FORMATION
TOP OF MISSISSIPPIAN ROCKS
Magoffin Marine zone?
Gin Creek coal
Low Splint coal
Taggart coal
Standiford coal
Imboden coal
Addington coal
Blair coal
GLADEVILLE SANDSTONE
Splash Dam coal
Upper Banner coal
Lower Banner coal
Raven coal
Jawbone coal
BEE ROCK SANDSTONE
BALD ROCK SANDSTONE
KANAWHA GROUP
NEW RIVER GROUP
POCAHONTAS GROUP
POTTSVILLE SERIES
FEET 2000
1500
1000
500
VERTICAL SCALE

Figure 48. (Continued).

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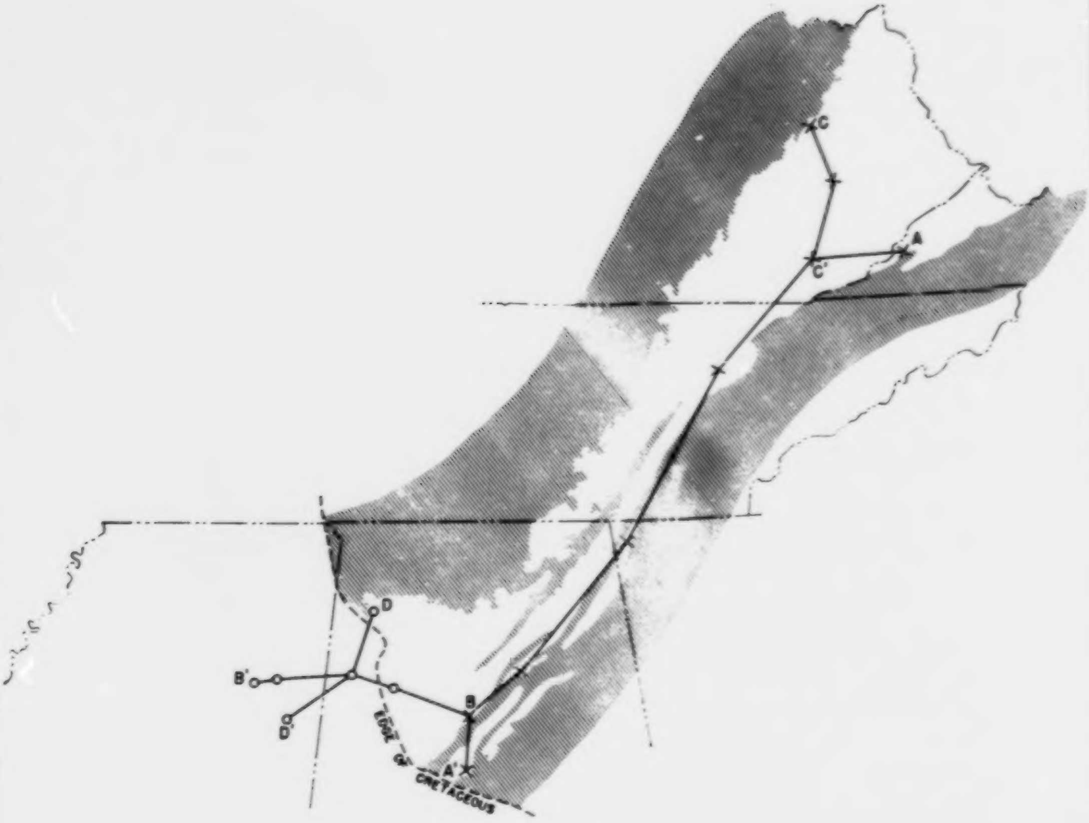
C
C'
A
A'
B
B'
D
D'
EDGE OF CRETACEOUS
0 25 50 75 100
SCALE OF MILES

Figure 49. Index map showing locations of stratigraphic sections (Strearns and Mitchem, 1962).

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In Eastern Kentucky, the Breathitt Formation of Middle Pennsylvanian-age outcrops over much of the coalfields. This formation contains some calcareous rocks, which make up a very small percentage of the strata (Huddle and others, 1963). Limestone occurs as thin beds of impure argillaceous, marine limestone such as the Magoffin Limestone in Bell and Knox Counties, Kentucky. Large concretions up to 0.6 m (2 ft) thick by 1.2 m (4 ft) in diameter are also found in some shales and siltstones.

Upper Mississippian carbonates in the western rim of the eastern Kentucky coalfields constitute the most important source of limestone aggregate in the region. These carbonates are exposed principally in the Pottsville Escarpment, extending northeastward across the state, along the western edge of the Cumberland Plateau.

The St. Genevieve Limestone is the most important quarry rock in this section (McGrain and Denver, 1967). The total limestone in the Pennsylvania section is estimated to be generally less than 0.1 percent of the entire strata (Wanless, 1946). Most authors characterize the depositional conditions as aqueous environments including shallow marine, lagoon, delta, lake, marsh, valley flat, and piedmont.

Several mining methods are encountered in the southern Appalachian coal regions. Historically, conventional contour strip mining, where spoil is cast downslope from the strip bench, has been practiced. Although still encountered to some extent in Alabama, recent legislation insures that other methods will become standard. The lateral movement or haulback methods, the box-cut contour method (mostly in Alabama), the modified block-cut method and, with limited application, modifications of area or mountaintop removal methods are among these other methods (Skelly and Loy, 1975).

EASTERN INTERIOR BASIN

Overview

The vast coalfields of western Kentucky, Illinois, and Indiana comprise the Eastern Interior Coal Basin. This area is significant not only in terms of total coal production but because of the high percentage of surface-mined coal. In 1973, this region provided about 31 percent of the total U.S. surface mine production. The Appalachian Region and the Eastern Interior Region differ significantly in geology and in the occurrence and mining of coal. Cyclic sedimentation is well displayed with at least 25 alterations of coal, marine limestone, shale, sandstone and underclay. The topography is, in general, level to gently rolling, except in southern Indiana, western Kentucky and locally, within southern Illinois and adjacent to major rivers where the terrain is slightly more rugged. Much of the surface is glaciated, and overburden characteristics are a special consideration in mining. These overburden characteristics account for the fact that, after mining, rather suitable quality drainage is produced from otherwise acid-producing strata.

Illinois is characterized by lowland plains, with few striking physiographic contrasts except near the southern edge of the field, where stream erosion is more pronounced. Although large-scale relief features are absent, the physiographic divisions of the state are readily apparent and assume great local significance. The greatest local relief is near major valleys, such as the Illinois and Kaskaskia River Valleys, especially within the driftless uplands of northwestern and southern Illinois. The total relief of the state is 297 m (973 ft). The local relief in most counties, however, is less than 61 m (200 ft).

A large part of the physiographic contrast is due to the topography of the bedrock surface and the extent and nature of glacial deposits that blanket the bedrock. Glacial drift is thin, averaging 15 m (less than 50 ft), and the bedrock is widely exposed in southern and western Illinois and the part of northeastern Illinois that is adjacent to the Illinois, Des Plaines, and Kankakee Rivers. The drift is thickest in the present major river valleys, in buried bedrock valleys and, regionally, in the northeast quarter of Illinois (which was covered by Wisconsinan glaciers). The drift is more than 61 m (200 ft) thick in some of the major valleys and beneath some of the moraines. It attains a maximum thickness of some 183 m (600 ft) in the Pawpaw Bedrock Valley in southeastern Lee County (Piskin and Bergstrom, 1967) (Figure 50). Annual precipitation in Illinois ranges from 784 to 1176 mm (32 to 48 in.). Agriculture is the dominant land use in the state; corn and soybeans are the principal crops.

The land forms of southwest Indiana are similar to those of Illinois, with local relief of 30 to 91 m (100 to 300 ft). About four-fifths of the coal-bearing region is covered by glacial drift. The predominant composition of these deposits is till, outwash sand and gravel, with lacustrine silt deposits in the broad valleys. The uplands adjacent to the Ohio and Wabash River Valleys are covered with thin, loess mantles.

The Wabash Lowland includes most of the outcrop of all major commercial coal beds in Indiana. This area has generally rolling topography with gentle slopes. The texture and local relief become rougher and greater to the east (Crawford Upland). Coals are exposed on hillsides or along streams. Mean annual precipitation ranges from 882 to 1078 mm (36 to 44 in.). Cropland with some pasture utilizes the bulk of the coal-bearing land. Towards the eastern edge of the field the land is forested.

Western Kentucky is similar in topography to southwest Indiana. However, the coal region is unglaciated. In general, the area may be characterized as an irregular plain, with about 30 to 91 m (100 to 300 ft) of local relief. Rainfall in the state averages about 1078 mm (44 in.) per year. Land use is primarily agricultural with some pasture and forested areas.

Mining Districts

Illinois--

Illinois is underlain by the largest coal-producing area in the United States, approximately 103,600 sq km (40,000 sq mi) (Figure 51), and this state is the heart of the Eastern Interior Coal Basin. The remaining strippable resources in Illinois are estimated to be 17,096 million metric

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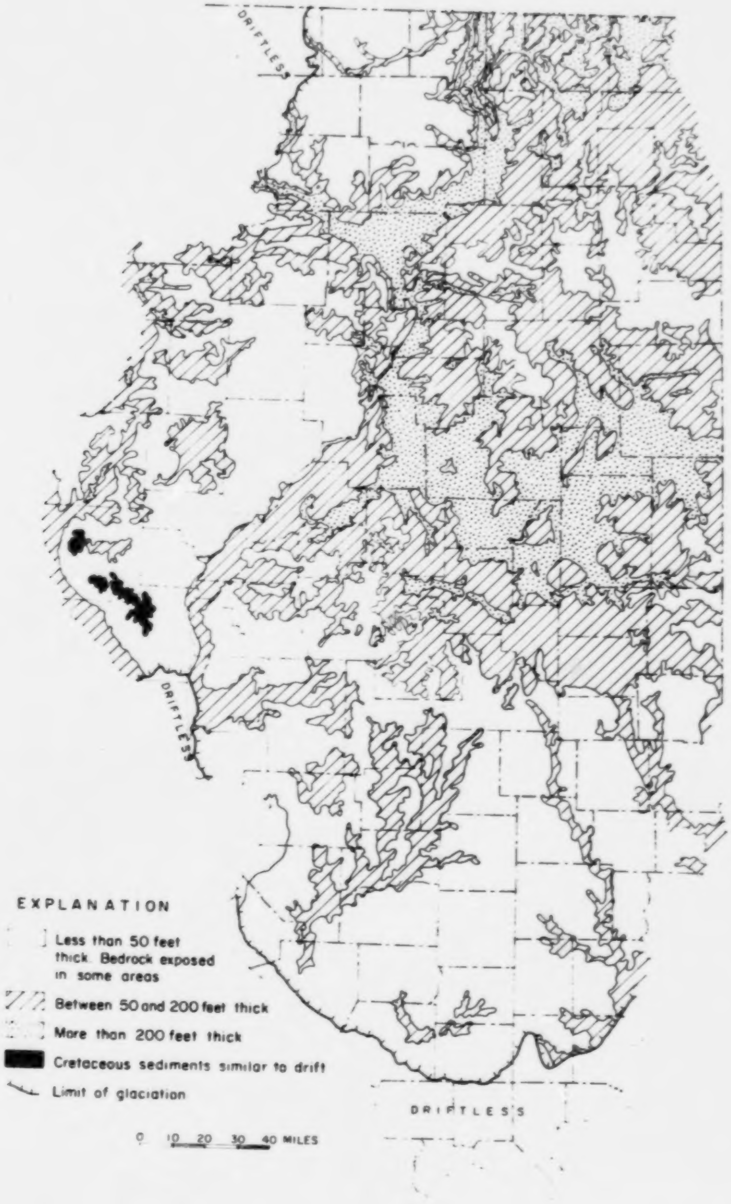
DRIFTLESS
DRIFTLESS
DRIFTLESS
EXPLANATION
Less than 50 feet thick. Bedrock exposed in some areas
Between 50 and 200 feet thick
More than 200 feet thick
Cretaceous sediments similar to drift
Limit of glaciation
0 10 20 30 40 MILES

Figure 50. Thickness of glacial drift in Illinois (Piskin and Bergstrom, 1967).

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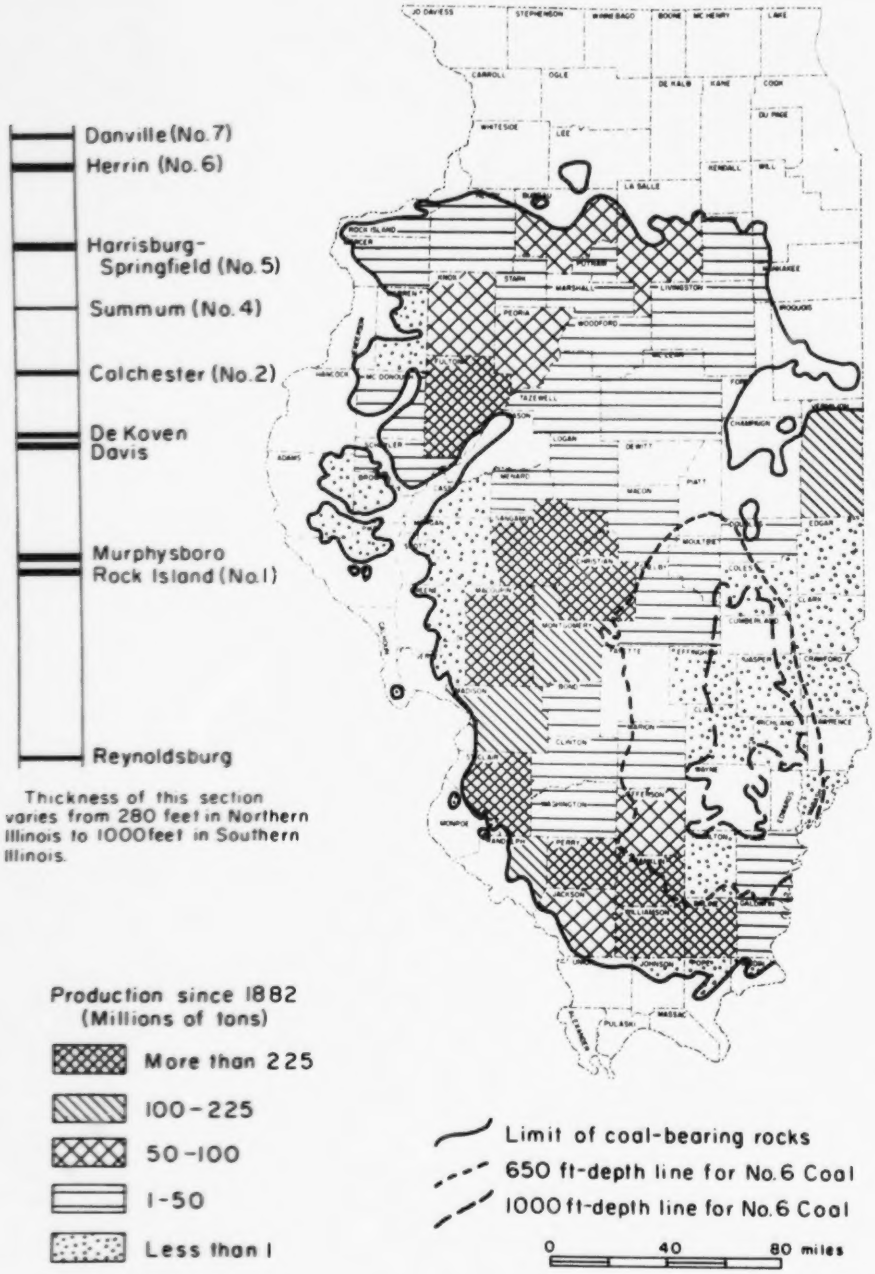
Danville (No. 7)
Herrin (No. 6)
Harrisburg-Springfield (No. 5)
Summum (No. 4)
Colchester (No. 2)
De Koven
Davis
Murphysboro
Rock Island (No. 1)
Reynoldsburg
Thickness of this section varies from 280 feet in Northern Illinois to 1000 feet in Southern Illinois.
Production since 1882 (Millions of tons)
More than 225
100-225
50-100
1-50
Less than 1
Limit of coal-bearing rocks
650 ft-depth line for No. 6 Coal
1000 ft-depth line for No. 6 Coal
0
40
80 miles
JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
COOK
DU PAGE
WHITESIDE
LEE
KENDALL
WILL
LA SALLE
ROCK ISLAND
STARK
PUTNAM
MARSHALL
LIVINGSTON
KNOX
PEORIA
WOODFORD
IROQUOIS
HANCOCK
MC DONOUGH
FULTON
MC LEAN
TAZEWELL
CHAMPAIGN
ADAMS
SCHUYLER
LOGAN
DEWITT
MENARD
MACON
PIATT
EDGAR
SANGAMON
MOULTRIE
CHRISTIAN
COLES
CLARK
MONTGOMERY
CUMBERLAND
FAYETTE
JASPER
CRAWFORD
MADISON
BOND
RICHLAND
LAWRENCE
CLINTON
MARION
WAYNE
JEFFERSON
MONROE
WASHINGTON
PERRY
JACKSON
WILLIAMSON
JOHNSON
PULASKI
MASSAC

Figure 51. Coal mining regions of Illinois within the Eastern Interior Region (Keystone Coal Industry Manual, 1975).

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tons (18,845 million tons) (USBM IC 8531, 1971). In recent years, Illinois has led the country in strip mining. Production in 1973 was 26,282 million metric tons (28,971 million tons).

The coals of Illinois, like those of Kentucky and Indiana, are usually referred to by number, although most coals are also known by geographic names. Using this double name scheme, the most important strippable coals in the state are the No. 1 - Rock Island Coal; No. 2 - Colchester Coal; No. 5 - Harrisburg or Springfield Coal; No. 6 - Herrin Coal and No. 7 - Danville Coal. The sulfur content of most Illinois coals is generally high, but ranges from essentially none to normally high values of 4 to 5 percent.

Indiana--

The coalfields of Indiana lie on the eastern edge of the Eastern Interior Coal Basin, covering about 16,835 sq km (6,500 sq mi) in the southwestern part of the state (Figure 52). Coal deposits occur in twenty-five counties in the state, but most strip production comes from Warrick, Clay, Sullivan, Pike, and Vigo Counties. In 1973, approximately 95 percent of the state's total production, 22.9 million metric tons (25.2 million tons), was strip mined.

The remaining strippable resources are estimated to be 2,487 million metric tons (2,741 million tons) (USBM IC 8531, 1971). There are at least 30 coals in Indiana that obtain mineable thickness of 0.6 m (2 ft) in places. However, only seven or eight seams are consistent enough to be mined over large areas. In general, the coal beds dip from 3.8 to 9.5 m per km (20 to 50 ft per mi) toward the southwest. Following are the coals that contain the largest strippable reserves: No. 5 - Springfield Coal; No. 3 - Seelyville Coal; No. 5 - Suivant Coal; and No. 7 - Danville Coal. These coals all average from 1.2 to 1.8 m (4 to 6 ft) in thickness. Most Indiana coals are medium (1 - 3 percent) or high sulfur, with mean values for most seams in the 2 - 4 percent range.

Western Kentucky--

Western Kentucky coalfields are deposits of the southeast extreme of the Eastern Interior Basin (Figure 46). This district supplies about 45 percent of Kentucky's total production, and most is from strip mining operations. The 1973 surface coal mine production in western Kentucky was 28,123 million metric tons (31,000 million tons). Current production is concentrated in eight counties: Butler, Daviess, Henderson, Hopkins, Muhlenberg, Ohio, Union, and Webster. The largest strippable resources are present in the No. 9, No. 11, No. 12, and No. 4 coals. Most coals from the western fields are high-sulfur coal.

Sedimentation Models

Pennsylvanian-aged coal-bearing sediments of the Eastern Interior Basin underlie approximately 137,269 sq km (53,000 sq mi) in Indiana, Illinois, and western Kentucky. Small extensions of this basin reach into parts of Missouri and Iowa. The strata are widely exposed throughout the basin except in parts of Illinois and Indiana, where the rocks are covered by Pleistocene-aged glacial till, loess, and lacustrine sediments or recent alluvial

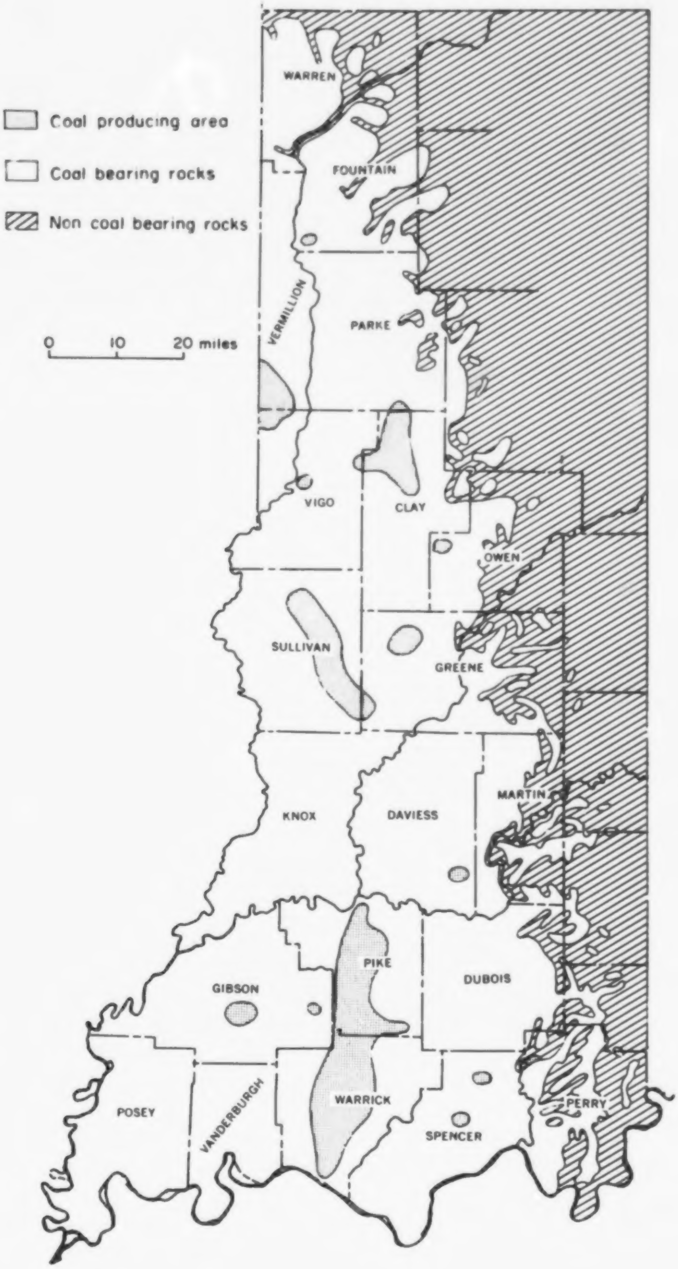
Coal producing area
Coal bearing rocks
Non coal bearing rocks
0
10
20 miles
WARREN
FOUNTAIN
VERMILLION
PARKE
VIGO
CLAY
OWEN
SULLIVAN
GREENE
KNOX
DAVIESS
MARTIN
GIBSON
PIKE
DUBOIS
POSEY
VANDERBURGH
WARRICK
SPENCER
PERRY

Figure 52. Coal mining regions of Indiana within the Eastern Interior Region (Keystone Coal Industry Manual, 1975).

sediments. The current, and most widely accepted, classification of rock-stratigraphic units of Pennsylvanian strata is given in Table 11 (Pryor and Sable, 1974, p. 304). There are three major units: the basal McCormick Group, dominantly fluviatile sandstones and shales; and the middle Kewanee and upper McLeansboro Groups, chiefly numerous cyclical alterations of thin limestones, shales, sandstones, and coals (Pryor and Sable, 1974).

The lithology of the basin sediments are largely shales and fine-grained sandstones with numerous beds of marine and non-marine limestone, coal, black slaty shale, and underclay. Sandy shale and siltstone make up nearly 40 percent of the McCormick Group rocks. Coals in this unit are thin and of limited areal extent. Limestones are rare and normally absent. The Kewanee Group is characterized by well-developed cyclic deposits (cyclothems) and, in contrast to the underlying McCormick Group, sandstone units constitute only 25 percent of the Spoon and Carbondale Formations (Pryor and Sable, 1974). Widespread limestones and coals are common, with the principal mineable coals in the Carbondale Formation.

The McLeansboro Group is comprised of cyclic units that are more marine in character than those of the underlying groups. The limestones are thicker and more numerous and the coals are thinner than in the Kewanee Group. The Modesto Formation is dominated by gray shales with argillaceous limestones, and locally well developed sandstone channel fills are also present. The Bond Formation is characterized by thick, widespread limestones and shale; the Millersville Limestone Member of the Bond Formation is commonly 6.1 to 9.1 m (20 to 30 ft) thick. The Mattoon Formation is dominated by shale and thick sandstone bodies, with thin argillaceous limestone units and thin coals (Pryor and Sable, 1974).

The thickness and outcrop area of the Caseyville, Abbott, and Spoon Formations are shown in Figure 53 (Wanless, 1962). The observer can see these lower units thicken to over 366 m (1,200 ft) along the southern edge of the basin, then to the north where the No. 2 coal is less than 30 m (100 ft) above the pre-Pennsylvanian-aged sediments. The combined Carbondale and Modesto Formations are represented on an isopach map in Figure 54 (Potter, 1962; Pryor and Sable, 1974). These sediments also thicken to the south becoming more than 213 m (700 ft) along the southern basin margin.

There are 50 recognized cyclothems in the Eastern Interior Basin. Wanless and others (1970) proposed that the general depositional environment of many of these alternating units is deltaic with associated alluvial plain sequences. These depositional systems entered the basin from the east-northeast and repeatedly prograded onto the marine platform. The initiation, growth, and abandonment of these deltaic lobes into a slowly subsiding basin resulted in the development of the cyclothems and their complex vertical and horizontal arrangement (Pryor and Sable, 1974). When we recognize that the mode of deposition was a constantly changing, near-shore environment, it becomes apparent that the variability among cyclothems within the basin is much higher than is sometimes supposed.

Regional studies by Wanless (1931a, 1931b) and Wanless and Weller (1932) showed the cyclothems to be extensive along the western part of this basin

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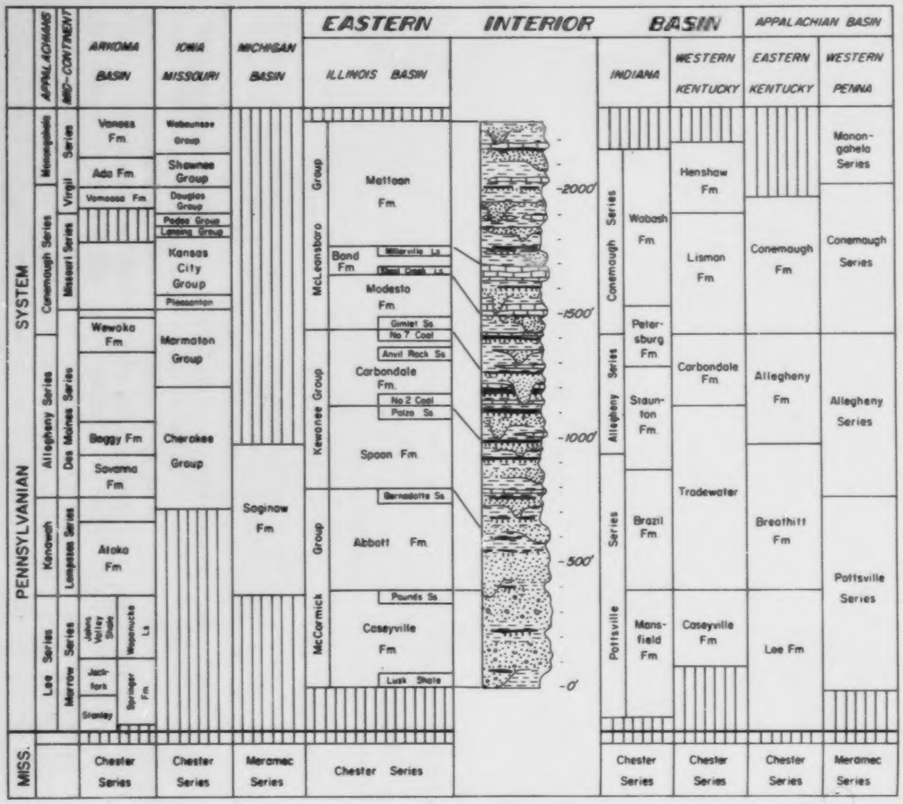
TABLE 11. CLASSIFICATION OF ROCK-STRATIGRAPHIC UNITS OF PENNSYLVANIA AGE (Pryor and Sable, 1974).


SYSTEM
PENNSYLVANIAN
MISS.
APPALACHIANS
MID-CONTINENT
ARKOMA BASIN
IOWA MISSOURI
MICHIGAN BASIN
EASTERN INTERIOR BASIN
ILLINOIS BASIN
INDIANA
WESTERN KENTUCKY
APPALACHIAN BASIN
EASTERN KENTUCKY
WESTERN PENNA
Monongahela
Conemaugh Series
Allegheny Series
Kanawha
Lee Series
Virgil Series
Missouri Series
Des Moines Series
Lampasas Series
Morrow Series
Vanoss Fm
Ada Fm
Vamoosa Fm
Wewoka Fm
Boggy Fm
Savanna Fm
Atoka Fm
Johns Valley Shale
Wapanucka Ls
Jackfork
Springer Fm
Stanley
Wabaunsee Group
Shawnee Group
Douglas Group
Pedee Group
Lansing Group
Kansas City Group
Pleasanton
Marmaton Group
Cherokee Group
Saginaw Fm
McLeansboro Group
Kewanee Group
McCormick Group
Mattoon Fm.
Bond Fm
Millersville Ls
Shoal Creek Ls
Modesto Fm
Gimlet Ss
No 7 Coal
Anvil Rock Ss
Carbondale Fm.
No 2 Coal
Palzo Ss
Spoon Fm
Bernadotte Ss
Abbott Fm.
Pounds Ss
Caseyville Fm
Lusk Shale
-2000'
-1500'
-1000'
-500'
-0'
Conemaugh Series
Allegheny Series
Pottsville Series
Wabash Fm
Petersburg Fm
Staunton Fm.
Brazil Fm
Mansfield Fm
Henshaw Fm
Lisman Fm
Carbondale Fm
Tradewater
Caseyville Fm
Conemaugh Fm
Allegheny Fm
Breathitt Fm
Lee Fm
Monongahela Series
Conemaugh Series
Allegheny Series
Pottsville Series
Chester Series
Chester Series
Meramec Series
Chester Series
Chester Series
Chester Series
Chester Series
Meramec Series

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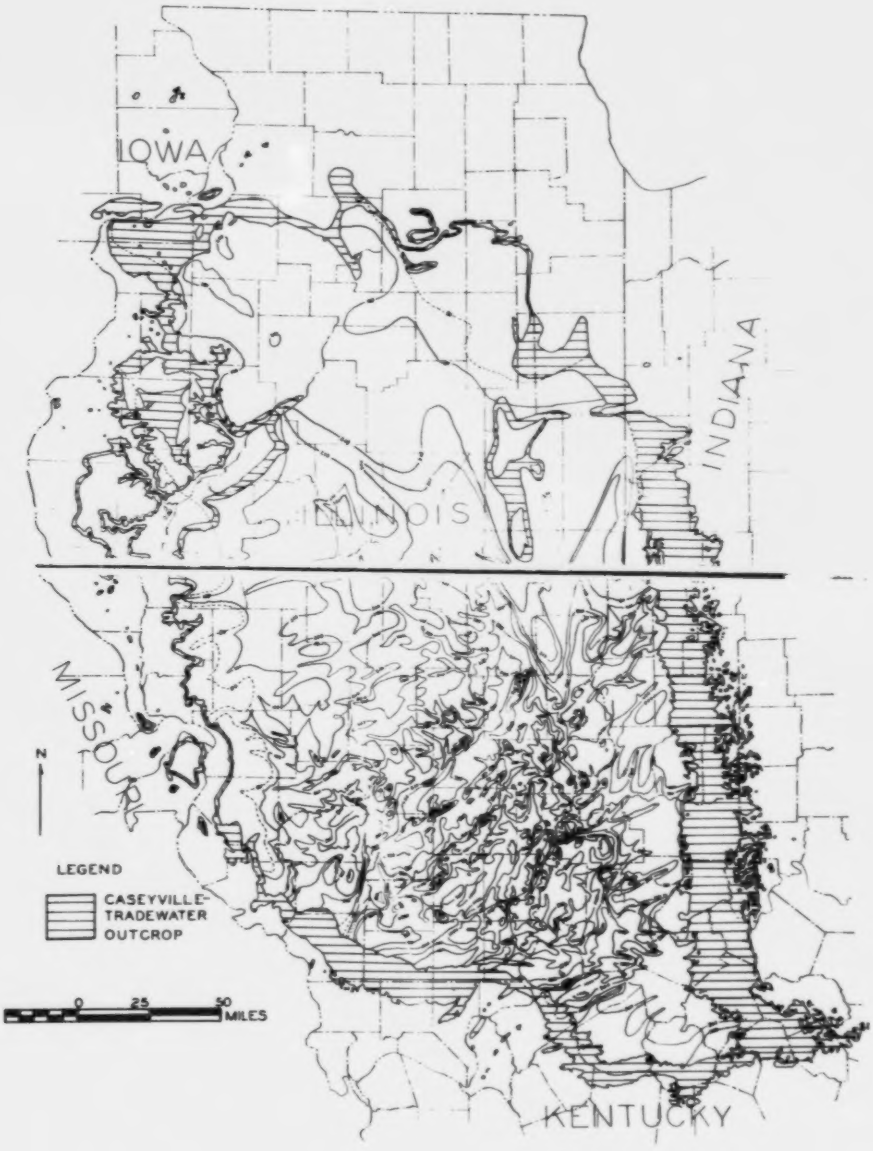
IOWA
ILLINOIS
INDIANA
MISSOURI
KENTUCKY
N
LEGEND
CASEYVILLE-TRADEWATER OUTCROP
0 25 50 MILES

Figure 53. Thickness and outcrop area of the Caseyville, Abbott and Spoon Formations of the Eastern Interior Region (Wanless, 1962).

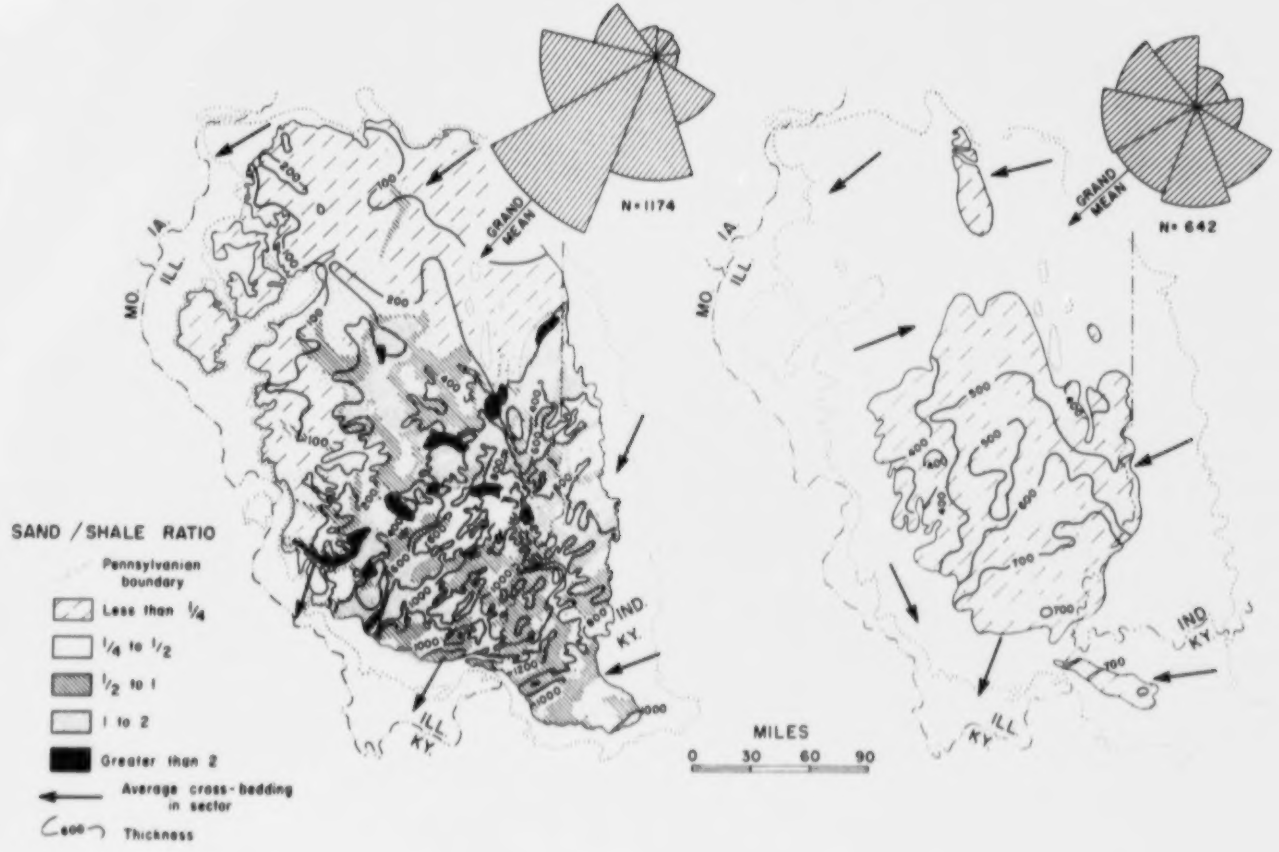
N=1174
GRAND MEAN
N=642
GRAND MEAN
MO
IA
ILL
IND
KY
ILL
KY
MILES
0
30
60
90
SAND / SHALE RATIO
Pennsylvanian boundary
Less than 1/4
1/4 to 1/2
1/2 to 1
1 to 2
Greater than 2
Average cross-bedding in sector
Thickness
100
200
400
500
600
700
800
900
1000
1200

Figure 54. Isopachous map of the Carbondale and Modesto Formations (Pryor and Sable, 1974).

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from its northern to its southern limits. Studies in southern Illinois indicate that in the thicker section there is a thickening of individual beds, additional beds that were not present in the cyclothems of other areas, and an addition of complete new cyclothems. It is apparent that the sequence of beds of the "ideal" cyclothem is fairly representative of western Illinois but that certain lithologies are more or less strongly developed in other areas (Wanless, 1962).

Occurrence of Limestone

Limestones within the Eastern Interior Basin tend to be rather impure, although the Livingston Limestone at Fairmount, Illinois (Vermilion County) has 96 percent calcium carbonate and the LaSalle Limestone at LaSalle, Illinois, 91 percent. Most limestones are composed in large part of shell detritus and interstitial fine-grained calcite (Wanless, 1965). This composition varies, however, along with properties such as color, grain size and bedding. Glass and Siever (1951) showed that some limestones, such as those in the Bankston Fork, have large quantities of dolomite, ankerite-dolomite, and siderite.

Most limestones are geographically extensive. The most common limestone pattern in Illinois is one with maximum development in the Ozark uplift flank area in St. Louis, thinning and wedging out at varying distances northeast, east, and southeast of the St. Louis region. Among key beds, the Hanover, Bankston Fork, Piasa-Cutler, and Carlinville generally follow this pattern.

The Seville, Minshall, Curlew, and Creal Springs Limestones are generally limited to restricted estuary-like basins of deposition, except in parts of western Kentucky; this is due, perhaps, to the inherited influence of pre-Pennsylvanian-aged topographic relief upon which the younger Pennsylvanian-aged sediments were deposited in western Kentucky. The Seahorne Limestone and Oak Grove marine beds are most prominent in the northwest part of the basin.

The St. David Limestone is best developed in a belt intermediate between the Ozark flank and the deeper part of the basin; north-central Illinois and western Indiana are representative areas. The Lonsdale Limestone is found in northern Illinois, dying out toward the Ozark flank area, and is probably continuous in the subsurface toward the south and east, with the middle or upper bench of the West Franklin and Madisonville, best developed in southeast Illinois, southern Indiana, and western Kentucky. The Breretone-Herrin-Providence Limestone is thickest near St. Louis, but unlike other limestones, it extends prominently into western Kentucky. The Trivoli Limestone is widespread and uniformly thin, as is its correlative in the Mid-Continent area, the Hertah Limestone. The Shoal Creek Limestone more nearly blankets the basin than does any other limestone, but it thins and may wedge out in southern Indiana and western Kentucky.

The Millersville Limestone is entirely restricted to the northern part of the basin; it wedges out a township or so south of its greatest development. The Omega, Shumway, and Greenup Limestones, likewise, seem to have restricted distribution in the central part of the basin (Wanless, 1965).

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In general, two basic types of surface mining are encountered in coal regions of the Eastern Interior Basin. Area mining is practiced where the overburden thickness is fairly constant, often in glaciated regions. Contour mining is found where coals outcrop on hillsides or in valleys and some of the overburden is too thick to remove economically. Specifically, the most common mining methods are the box-cut or modified area mining techniques.

MICHIGAN BASIN

The coalfields of the Michigan Basin occupy the central part of the southern peninsula of Michigan. These strata cover an area of about 29,927 sq km (11,555 sq mi), of which a small section is considered strippable. In the past, most surface mining has been confined to the southwestern portion of the basin, where the Pennsylvanian-aged rocks are nearest the surface. Production has declined steadily since the early 1900's because of the general unsuitability of the coal for profitable mining.

The coals of Michigan occur in the Saginaw Formation, which is considered equivalent to the lower part of the Allegheny Formation in the Appalachian Basin. The beds dip toward the center of the basin, at an average gradient of between 2.1 and 3.8 m per km (11 to 20 ft per mi), and reach a maximum depth below surface of 293 m (960 ft) in north-central Midland County. Although locally numerous, the coal beds are thin and of limited areal extent. Few of the beds that have been mined average more than 0.9 m (3 ft) in thickness. Only three seams are of economic significance: the Saginaw, the Lower Verne, and the Upper Verne, and these are relatively thin.

The noncontinuous nature of much of the Saginaw Formation is due to the localized stream and swamp depositional environments. Local unconformities in the exposures of the Saginaw rocks are abundant. In general, the formation consists of gray to black shale, sandstone, shaly/limestone, and coals. Calcareous shales and argillaceous limestones of marine origin are more laterally persistent than other beds. Several cycles of continental and marine deposition have been found by Kelly (1933). Michigan coal is ranked as high-violative B and C bituminous. Sulfur content ranges from 1 to 3 percent. Michigan coal is generally suitable for domestic and industrial fuel use.

The land surface in the southeastern part of the Michigan Coal Basin is flat or undulating, with local relief rarely exceeding 30 m (100 ft). Pleistocene glacial deposits cover most of the area of coal-bearing rocks. Drift deposits are generally less than 61 m (200 ft) and may be locally absent in areas where mining has been important in the past (principally Eaton, Ingham, Shiawassee, Saginaw, and Bay counties). In places, pre-Pleistocene drainage valleys have cut coal-bearing rocks and replaced them with unconsolidated glacial drifts. Since most of the coal in Michigan is below the water table, groundwater seepage from permeable drift deposits is common in mines located in or near such sediments.

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WESTERN INTERIOR BASIN

Coals of the Western Interior Province, or the Mid-Continent Region, occur in a somewhat discontinuous manner over a broad expanse of territory. Coal-bearing areas encompass southern Iowa, southeastern Nebraska, eastern Kansas, northern and western Missouri, northwestern Arkansas, and eastern Oklahoma. There is not as much coal production within these states as there is in many of the other states covered in this report.

With the exception of Iowa, almost all the coal that is extracted from the ground is surface mined. In 1973, this region accounted for about 3 percent of U.S. surface coal mine production. In 1973 in the Western Interior Basin, strip-mine production among the states ranged from 0.45 million metric tons (.5 million tons) in Iowa to 4.5 million metric tons (5.0 million tons) in Missouri. Missouri also has the largest remaining strippable resources, 3,107 billion metric tons (3,425 billion tons) (USBM IC 8531, 1971).

Coal-bearing rocks of the Western Interior Province are all of Pennsylvanian age and are found principally in the depositional area of the Forest City Basin, the Cherokee Platform, and the Arkoma Basin (Figure 55). The Arkoma Basin is a wedge of thick, geosynclinal rocks of the Atokan and Desmoinesian Age. The geosyncline was filled and was inactive in late Pennsylvanian time. The Pennsylvanian in the mid-continent area as a whole is divided into five series--the Morrowan Series at the base (Figure 56), Atokan (Figure 57), Desmoinesian, Missourian, and Virgilian Series (Table 12) (Branson, 1962). A map of the principal occurrence of coals in this region is given in Figure 58.

Mining Districts

Arkansas--

The bituminous coalfield in Arkansas is located in the west-central part of the state (Figure 59). The coalfield is approximately 53 by 99 km (33 mi wide by 60 mi long) and occupies parts of seven counties. All the coal beds are in the lower part of the Pennsylvanian System, and are part of the Arkoma Basin depositional feature (see Figure 55). The remaining strippable resource is 0.18 billion metric tons (0.2 billion tons of coal) (1968). Strip-mine production in 1973 was 132 billion metric tons (146 million tons) or 99 percent of Arkansas' total production. Although over 19 coal beds are known in the Arkansas coalfields, only a few are considered to be economically significant. These are the Lower and Upper Hartshorne, Charleston, and the Paris. Arkansas contains significant deposits of lignite located in the southern and northeastern parts of the state within the Gulf Province.

Iowa--

In Iowa, coal-bearing rocks of Pennsylvanian age cover about 51,800 sq km (20,000 sq mi) of the southern part of the state (Figure 60). The coal resources are part of the Forest City Basin depositional features (see Figure 55). Much of the surface material covering the state is glacial debris. The presence of these glacial deposits, and their water-bearing nature, has adversely affected coal mining. Strip-mine production in Iowa

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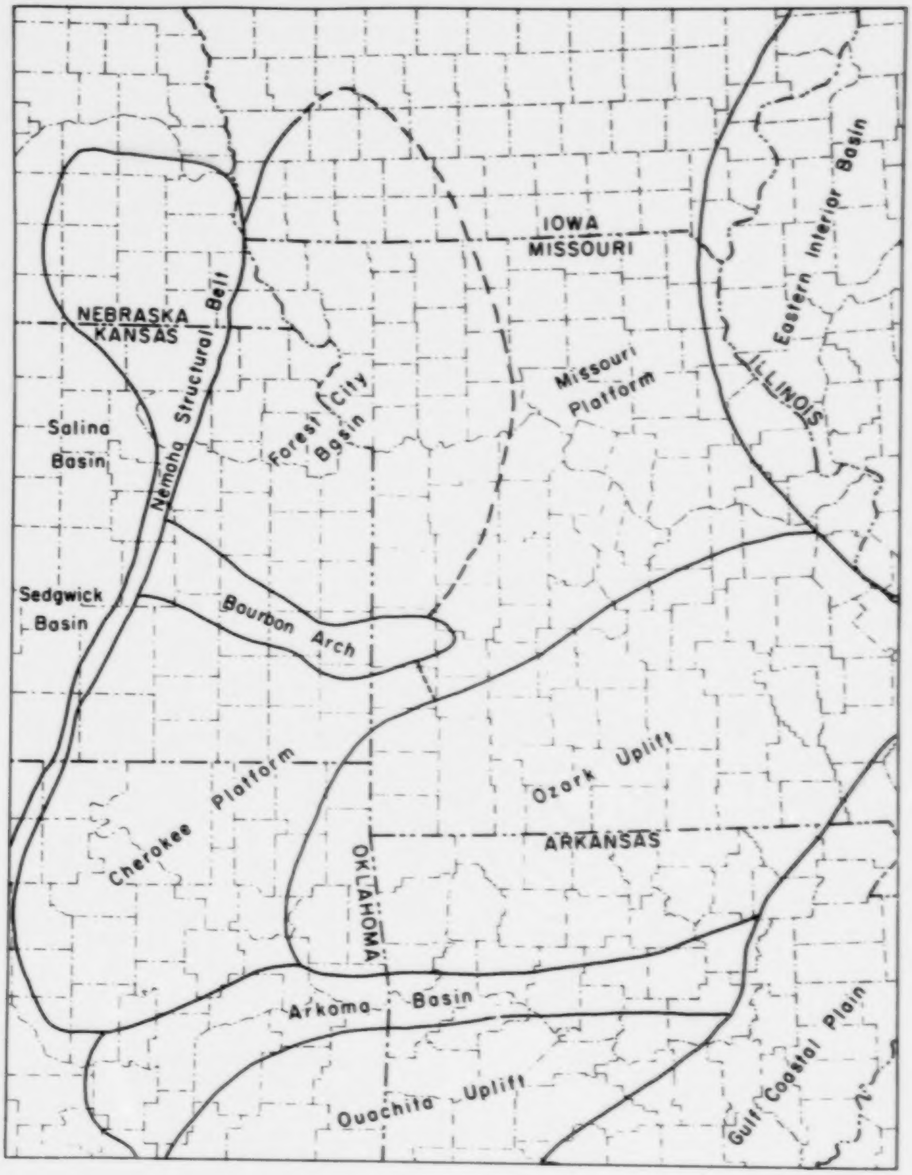
IOWA
MISSOURI
NEBRASKA
KANSAS
Nemaha Structural Belt
Salina Basin
Forest City Basin
Missouri Platform
Eastern Interior Basin
ILLINOIS
Sedgwick Basin
Bourbon Arch
Ozark Uplift
ARKANSAS
Cherokee Platform
OKLAHOMA
Arkoma Basin
Ouachita Uplift
Gulf Coastal Plain

Figure 55. Major Pennsylvanian structural features of the Mid-Continent (Branson, 1962).

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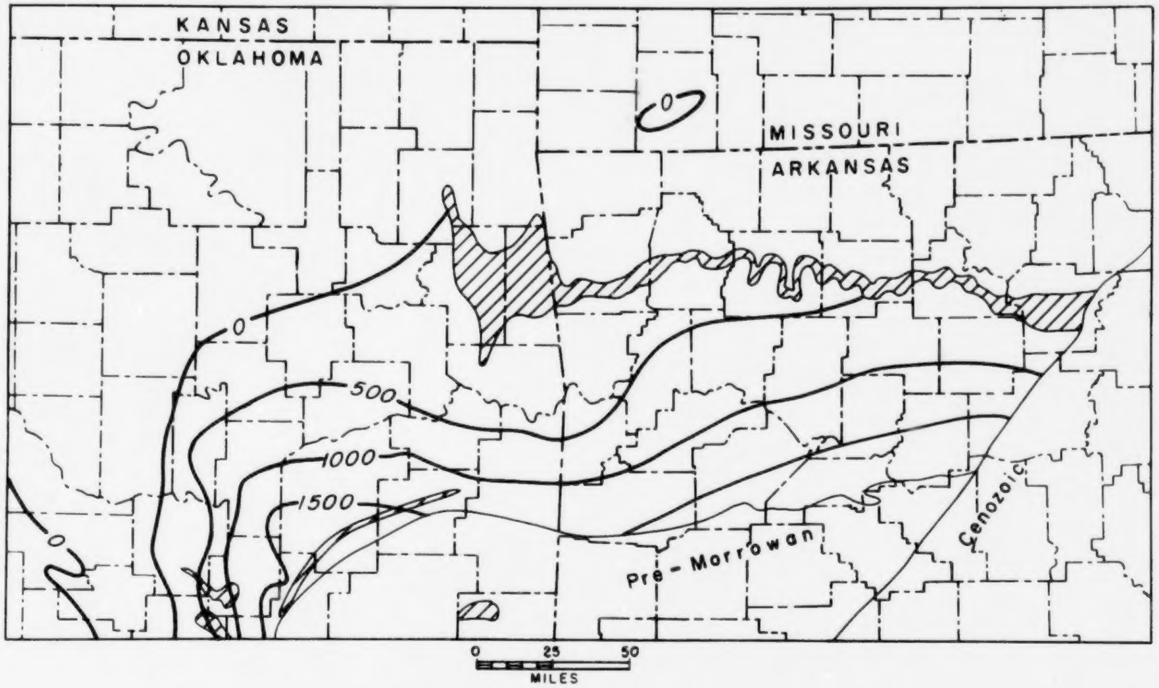
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS
0
0
0
500
1000
1500
Pre-Morrowan
Cenozoic
0
25
50
MILES

Figure 56. Distribution and isopachous map of the Morrowan Series or the earliest Pennsylvania Series in the Mid-Continent region. Cross-hatching indicates the area of outcrop of Morrowan rocks (Branson, 1962).

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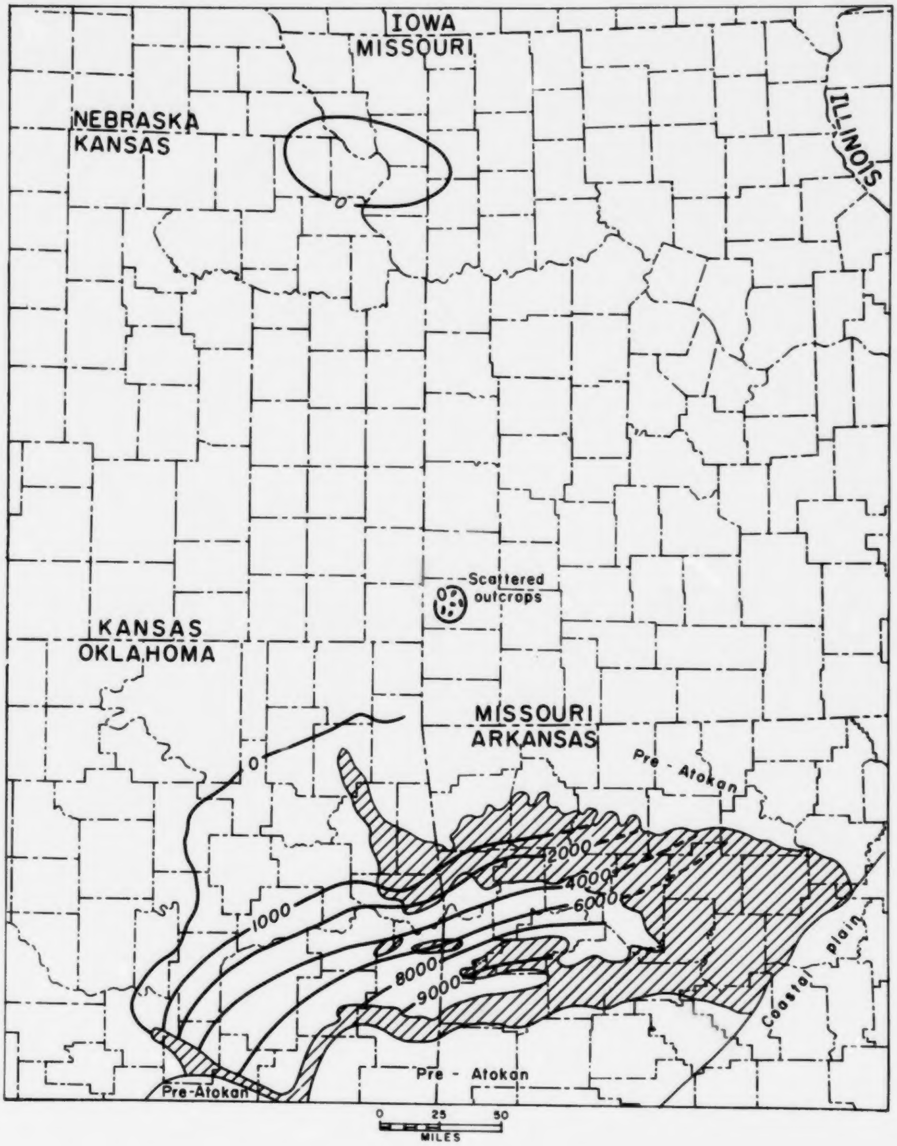
IOWA
MISSOURI
NEBRASKA
KANSAS
ILLINOIS
0
Scattered outcrops
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS
Pre - Atokan
0
2000
4000
6000
1000
8000
9000
Coastal plain
Pre - Atokan
Pre-Atokan
0
25
50
MILES

Figure 57. Distribution and isopachous map of the Atokan Series. Cross-hatching indicates area of outcrop of Atokan rocks (Branson, 1962).

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TABLE 12. GROUPS OF THE PENNSYLVANIAN SYSTEM IN THE MID-CONTINENT
(Source: Branson, 1962)

State Series	Oklahoma-Arkansas	Kansas-Nebraska	Missouri	Iowa
Virgilian	not divided	Wabaunsee Shawnee Douglas	Wabaunsee Shawnee Douglas	Wabaunsee Shawnee Douglas
Missourian	Ochelata Skiatook	Pede Lansing Kansas City Pleasanton	Pede Lansing Kansas City Pleasanton	Pede Lansing Kansas City Pleasanton
Desmoinesian	Marmation Cabaniss Krebs	Marmation Cherokee	Marmation Cherokee	Appanoose Cherokee
Atokan	not divided	not divided	not divided	absent
Morrowan	not divided	absent	absent	absent

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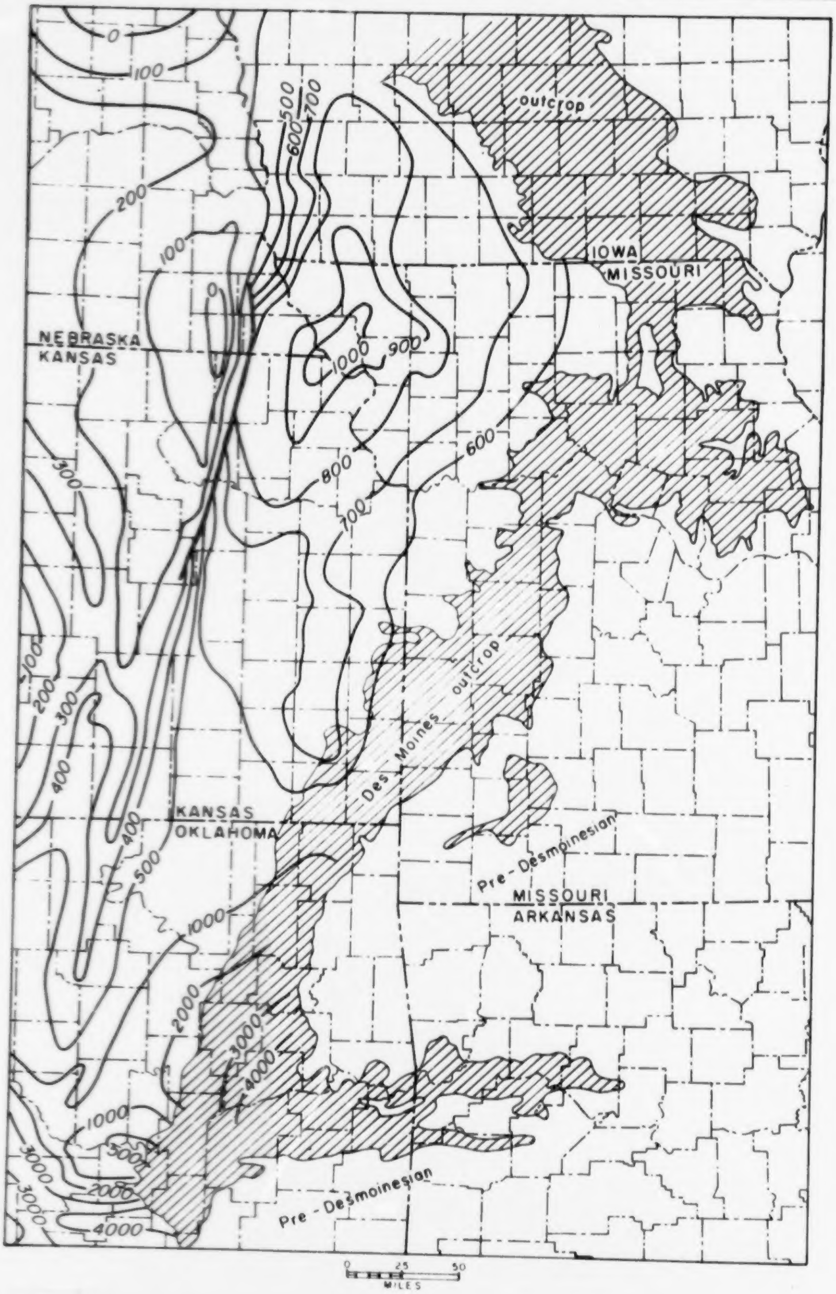
0
100
200
100
0
500
600
700
outcrop
IOWA
MISSOURI
NEBRASKA
KANSAS
1000
900
800
700
600
300
100
200
300
400
400
500
KANSAS
OKLAHOMA
Des Moines outcrop
Pre-Desmoinesian
MISSOURI
ARKANSAS
1000
2000
3000
4000
1000
5000
3000
2000
3000
4000
Pre-Desmoinesian
0 25 50
MILES

Figure 58. Distribution and isopachous map of the Desmoinesian Series of the Mid-Continent Region. Cross-hatching indicates areas of outcrop of Desmoinesian rocks (Branson, 1962).

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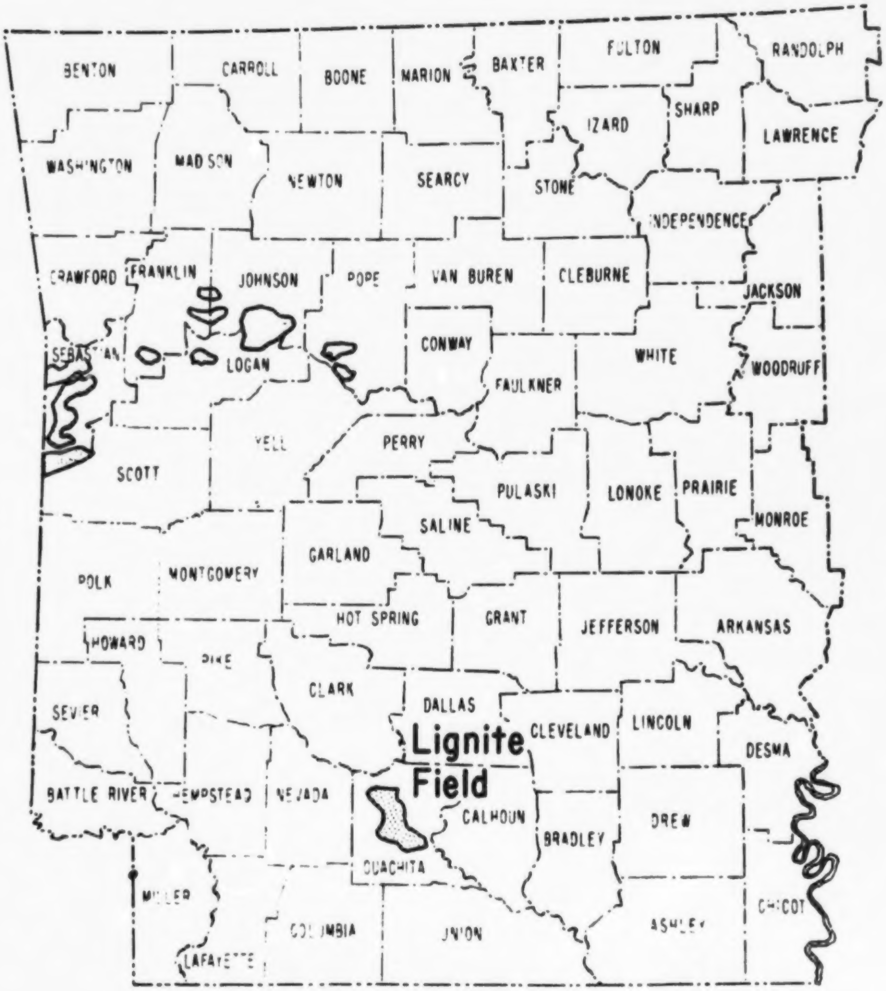
BENTON
CARROLL
BOONE
MARION
BAXTER
FULTON
RANDOLPH
IZARD
SHARP
LAWRENCE
WASHINGTON
MADISON
NEWTON
SEARCY
STONE
INDEPENDENCE
CRAWFORD
FRANKLIN
JOHNSON
POPE
VAN BUREN
CLEBURNE
JACKSON
SEBASTIAN
LOGAN
CONWAY
WHITE
WOODRUFF
FAULKNER
YELL
PERRY
SCOTT
PULASKI
LONOKE
PRAIRIE
MONROE
SALINE
GARLAND
POLK
MONTGOMERY
HOT SPRING
GRANT
JEFFERSON
ARKANSAS
HOWARD
PIKE
CLARK
DALLAS
CLEVELAND
LINCOLN
DESMA
SEVIER
Lignite Field
BATTLE RIVER
HEMPSTEAD
NEVADA
CALHOUN
BRADLEY
DREW
OUACHITA
MILLER
COLUMBIA
UNION
ASHLEY
CHICOT
LAFAYETTE

Figure 59. Coal distribution in Arkansas (Keystone Coal Industry Manual, 1975).

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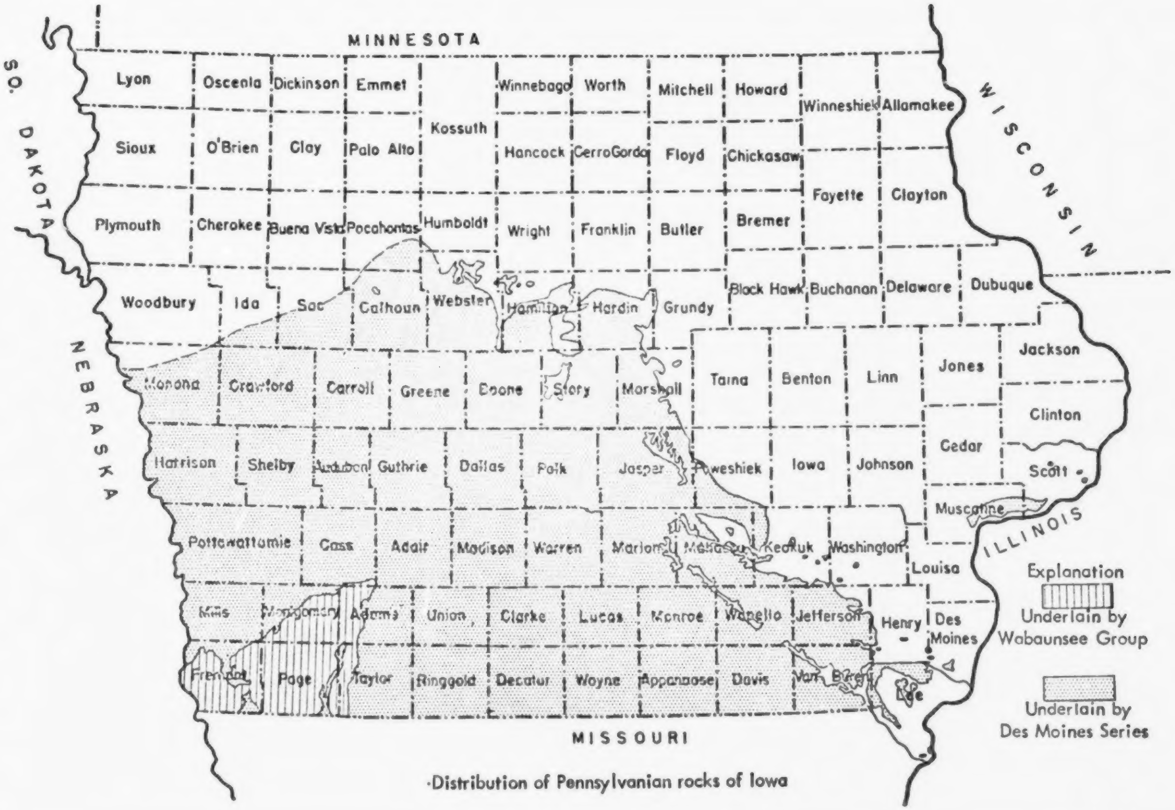
MINNESOTA
WISCONSIN
ILLINOIS
MISSOURI
NEBRASKA
SO. DAKOTA
Lyon
Osceola
Dickinson
Emmet
Kossuth
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O'Brien
Clay
Palo Alto
Hancock
CerroGordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Black Hawk
Buchanan
Delaware
Dubuque
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Tama
Benton
Linn
Jones
Jackson
Clinton
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Cedar
Scott
Muscatine
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Explanation
▥ Underlain by Wabaunsee Group
▨ Underlain by Des Moines Series
Distribution of Pennsylvanian rocks of Iowa

Figure 60. Distribution of Pennsylvanian-aged rocks of Iowa (Keystone Coal Industry Manual, 1975).

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in 1973 was 0.43 million metric tons (.47 million tons). This represents about 55 percent of Iowa's total production from all types of mining. The remaining strippable coal resource in Iowa is 0.9 billion metric tons (1 billion tons) (USBM IC 8531, 1971).

Coal in Iowa is present throughout most of the Pennsylvanian, but seams of economic importance occur only in the Wabaunsee Group of the Virgilian Series, and the Marmation and Upper and Lower Cherokee Groups of the Desmoinesian Series (Table 12). Three coals are recognized in the Wabaunsee Group, but only one is commercially important. The Desmoinesian Series makes up the lower part of the Pennsylvanian System in Iowa. The Marmation Group of this series contains four named coal seams. The Cherokee Group contains a series of relatively thick coal seams, although they are not continuous over large areas. Six named coal seams occur in the Upper Cherokee, and eight in the Lower Cherokee (USBM IC 8531, 1971).

Kansas--

Coal-bearing rocks in Kansas occur in the eastern portion of the state primarily as part of the Forest City Basin and Cherokee Platform (Figures 55 and 61). The greatest production comes from several counties in the southeastern field. Production in 1973 was 1.0 million metric tons (1.1 million tons), all of which was mined by surface methods. The remaining strippable coal resource in Kansas is 1.3 billion metric tons (1.4 billion tons) (USBM IC 8531, 1971). The most important coals currently mined are the Mineral, Fleming, and Bevier coals. Kansas coals are predominantly flat-lying and relatively free of faulting. Overburden to coal thickness ratios for Kansas coal mining operations are the highest known for the United States, attaining ratios of 30 and 35:1 (Keystone Coal Industry Manual, 1975).

Missouri--

Missouri coal deposits underlie approximately 59,570 sq km (23,000 sq mi) of the northern and western counties of the state (Figure 62). The coal-bearing rocks are part of the Forest City Basin feature (see Figure 55). The beds dip in a generally northwesterly direction and the depth to the coal increases in the direction of dip. Much of the coal is thick, so depth to the coal has been an important factor in mining. All of Missouri's 1973 production of 4.5 million metric tons (5 million tons) of coal was strip mined. Twenty-nine counties are underlain by coal that is available for strip mining. The most important coal beds are the Weir-Pittsburgh, Tebo, Mineral, Croweburg, Fleming, Bevier, Mulley, Mulberry, and Rowe and Drywood coals. Missouri's remaining strippable resource is about 3.1 billion metric tons (3.4) billion tons of coal (USBM IC 8531, 1971).

Oklahoma--

The coal-bearing strata of eastern Oklahoma occur over an area of about 37,697 sq km (14,555 sq mi) (Figure 63). Coal is found in 24 counties, primarily in the east-central and northeastern parts of the state. This area includes strata of both the Cherokee Platform and the Arkoma Basin (see Figure 55). Coal-bearing formations consist chiefly of sandstone and shale with some limestone north of the Arkansas River.

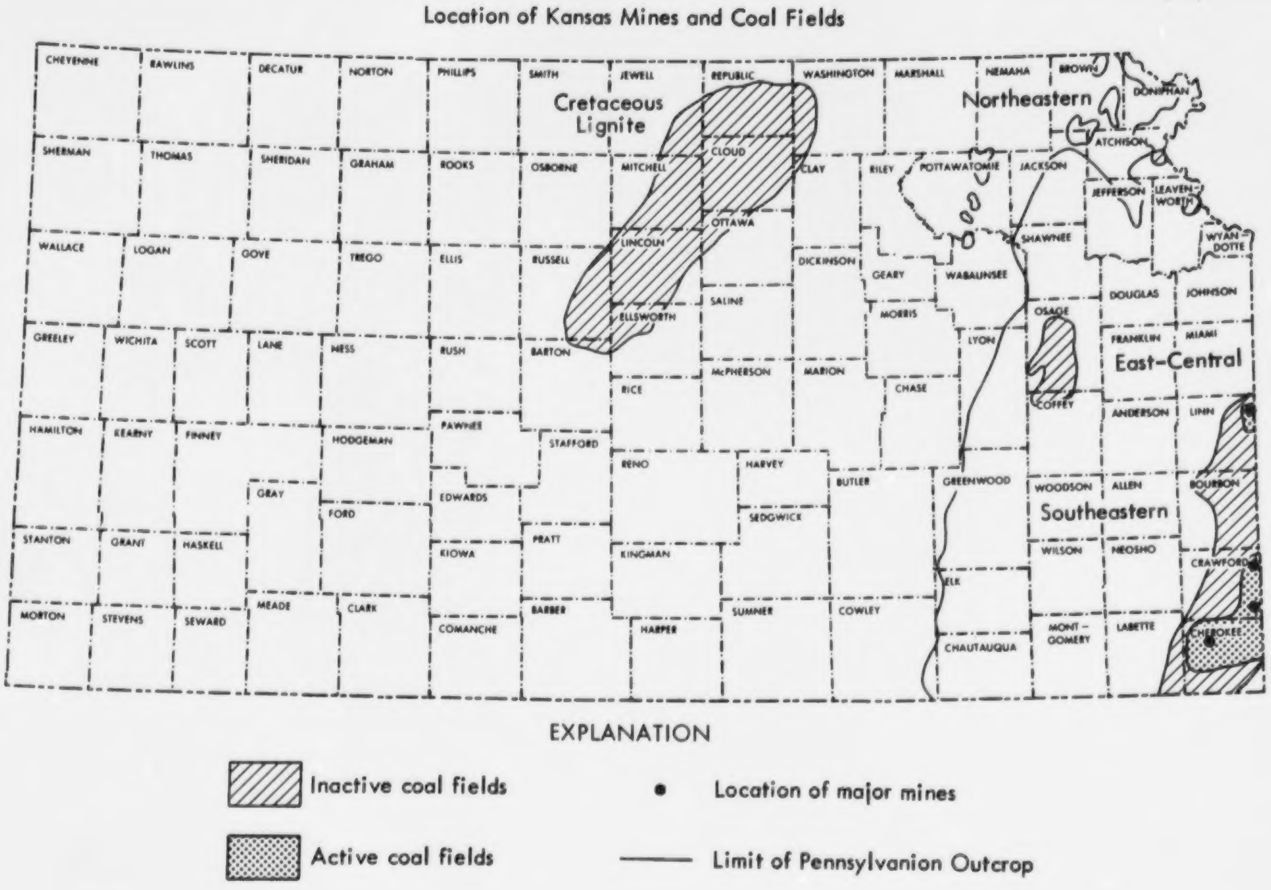
Location of Kansas Mines and Coal Fields
Cretaceous Lignite
Northeastern
East-Central
Southeastern
CHEYENNE
RAWLINS
DECATUR
NORTON
PHILLIPS
SMITH
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
ATCHISON
SHERMAN
THOMAS
SHERIDAN
GRAHAM
ROOKS
OSBORNE
MITCHELL
CLOUD
CLAY
RILEY
POTTAWATOMIE
JACKSON
JEFFERSON
LEAVENWORTH
WYANDOTTE
WALLACE
LOGAN
GOVE
TREGO
ELLIS
RUSSELL
LINCOLN
OTTAWA
DICKINSON
GEARY
WABAUNSEE
SHAWNEE
DOUGLAS
JOHNSON
GREELEY
WICHITA
SCOTT
LANE
NESS
RUSH
BARTON
ELLSWORTH
SALINE
MORRIS
LYON
OSAGE
FRANKLIN
MIAMI
RICE
McPHERSON
MARION
CHASE
COFFEY
ANDERSON
LINN
HAMILTON
KEARNY
FINNEY
HODGEMAN
PAWNEE
STAFFORD
RENO
HARVEY
BUTLER
GREENWOOD
WOODSON
ALLEN
BOURBON
GRAY
FORD
EDWARDS
SEDGWICK
STANTON
GRANT
HASKELL
KIOWA
PRATT
KINGMAN
WILSON
NEOSHO
CRAWFORD
ELK
MORTON
STEVENS
SEWARD
MEADE
CLARK
COMANCHE
BARBER
HARPER
SUMNER
COWLEY
CHAUTAUQUA
MONTGOMERY
LABETTE
CHEROKEE
EXPLANATION
Inactive coal fields
Active coal fields
Location of major mines
Limit of Pennsylvanian Outcrop

Figure 61. Location of Kansas mines and coalfields (Keystone Coal Industry Manual, 1975).

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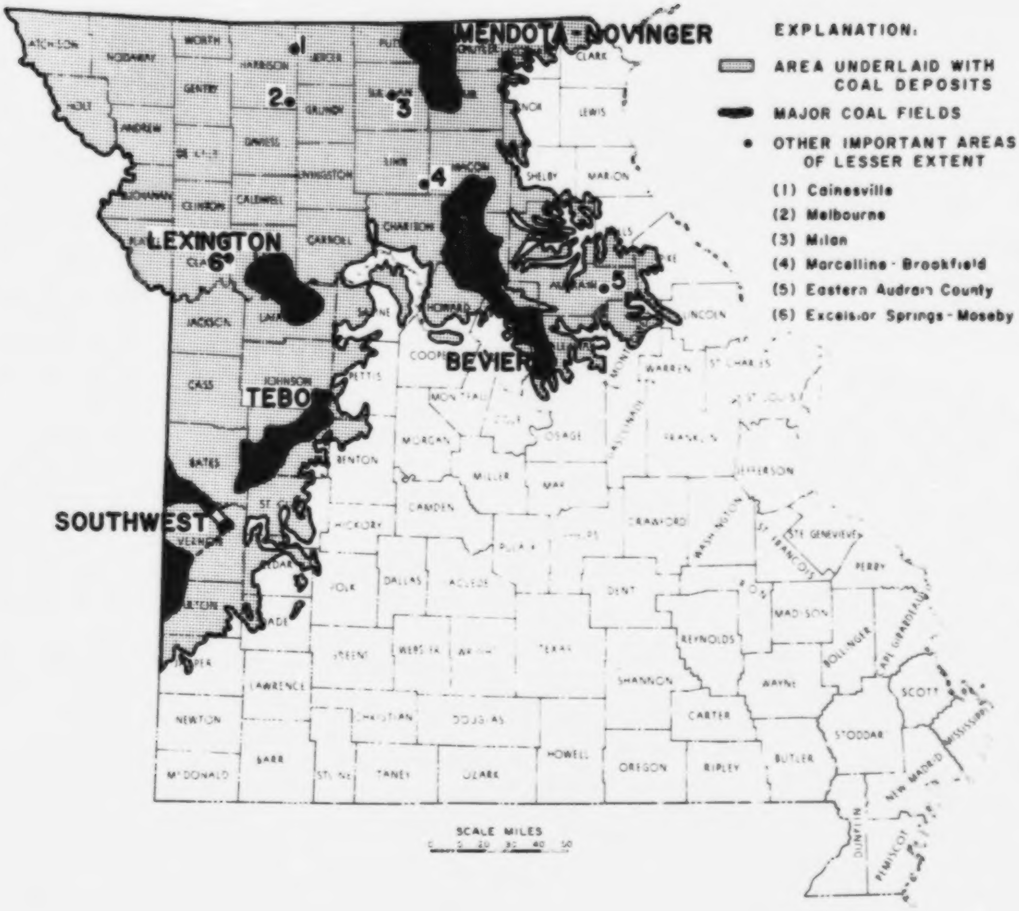
MENDOTA-NOVINGER
LEXINGTON
BEVIER
TEBO
SOUTHWEST
EXPLANATION:
AREA UNDERLAID WITH COAL DEPOSITS
MAJOR COAL FIELDS
OTHER IMPORTANT AREAS OF LESSER EXTENT
(1) Cainesville
(2) Melbourne
(3) Milan
(4) Marceline - Brookfield
(5) Eastern Audrain County
(6) Excelsior Springs - Moseby
SCALE MILES
0 5 10 20 30 40 50
ATCHISON
NODAWAY
WORTH
HARRISON
MERCER
PUTNAM
SCHUYLER
CLARK
HOLT
ANDREW
GENTRY
GRUNDY
SULLIVAN
KNOX
LEWIS
DEKALB
DAVIESS
LINN
MACON
SHELBY
MARION
BUCHANAN
CLINTON
CALDWELL
LIVINGSTON
CHARITON
CARROLL
CLAY
JACKSON
HOWARD
COOPER
LINCOLN
WARREN
ST CHARLES
ST LOUIS
CASS
JOHNSON
PETTIS
MONITEAU
COLE
OSAGE
FRANKLIN
BATES
BENTON
MORGAN
MILLER
MARIES
JEFFERSON
VERNON
HICKORY
CAMDEN
CRAWFORD
WASHINGTON
STE GENEVIEVE
ST FRANCOIS
PERRY
CEDAR
POLK
DALLAS
LACLEDE
DENT
MADISON
BARTON
DADE
REYNOLDS
BOLLINGER
CAPE GIRARDEAU
JASPER
GREENE
WEBSTER
WRIGHT
TEXAS
SHANNON
WAYNE
SCOTT
LAWRENCE
CARTER
NEWTON
CHRISTIAN
DOUGLAS
STODDARD
MISSISSIPPI
BARRY
HOWELL
OREGON
RIPLEY
BUTLER
MDONALD
STONE
TANEY
OZARK
NEW MADRID
DUNKLIN
PEMISCOT

Figure 62. Distribution of Missouri coalfields (Keystone Coal Industry Manual, 1975).

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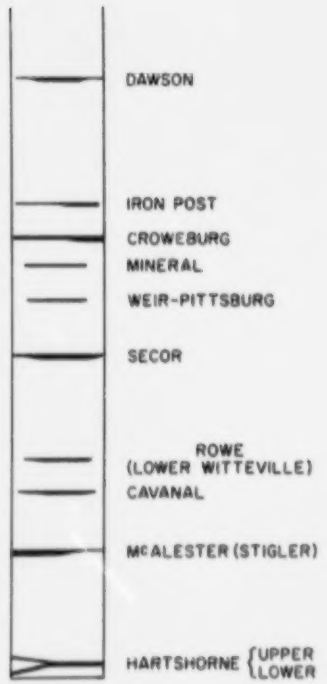
DAWSON
IRON POST
CROWEBURG
MINERAL
WEIR-PITTSBURG
SECOR
ROWE
(LOWER WITTEVILLE)
CAVANAL
McALESTER (STIGLER)
HARTSHORNE {UPPER
LOWER

The thickness of this generalized geologic column ranges from 1,000 feet in the Northeast Oklahoma shelf to 6,000 feet in the Arkoma basin.

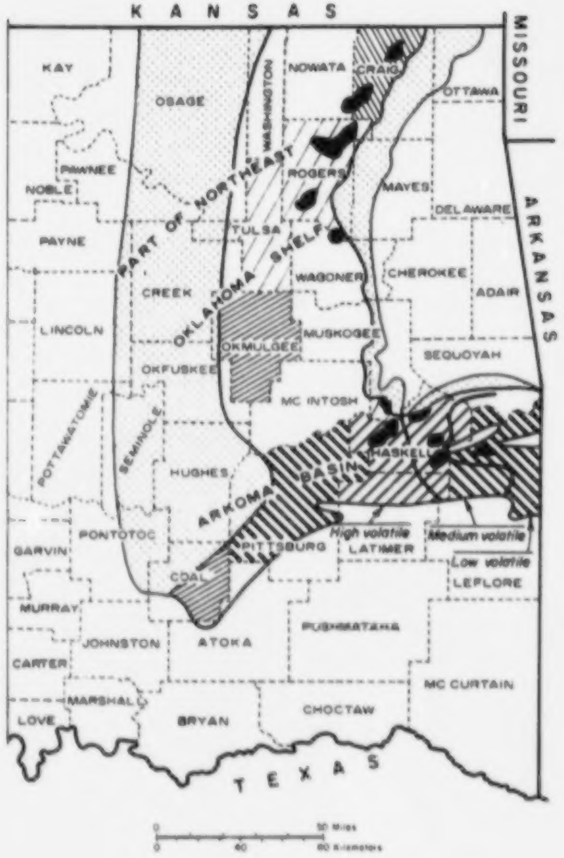
KANSAS
MISSOURI
ARKANSAS
TEXAS
KAY
OSAGE
WASHINGTON
NOWATA
CRAIG
OTTAWA
PAWNEE
NOBLE
ROGERS
MAYES
DELAWARE
PAYNE
TULSA
PART OF NORTHEAST
OKLAHOMA SHELF
WAGONER
CHEROKEE
ADAIR
CREEK
LINCOLN
OKMULGEE
MUSKOGEE
SEQUOYAH
OKFUSKEE
MC INTOSH
POTTAWATOMIE
SEMINOLE
HUGHES
HASKELL
ARKOMA BASIN
PONTOTOC
GARVIN
PITTSBURG
LATIMER
High volatile
Medium volatile
Low volatile
LEFLORE
COAL
MURRAY
JOHNSTON
ATOKA
PUSHMATAHA
CARTER
MC CURTAIN
MARSHALL
LOVE
BRYAN
CHOCTAW
0
50 Miles
0
40
80 Kilometers

Figure 63a. Distribution by county of remaining resources of bituminous coal in Oklahoma, as of January 1, 1971, and area of present and recent coal mining (in black) (Keystone Coal Industry Manual, 1975).

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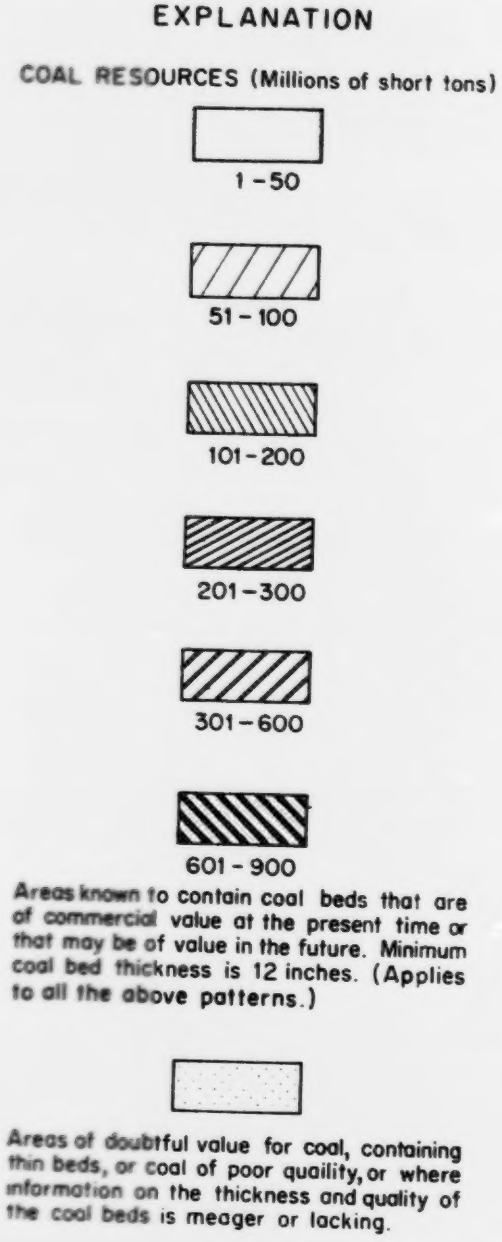

EXPLANATION
COAL RESOURCES (Millions of short tons)
1-50
51-100
101-200
201-300
301-600
601-900

Areas known to contain coal beds that are of commercial value at the present time or that may be of value in the future. Minimum coal bed thickness is 12 inches. (Applies to all the above patterns.)

Areas of doubtful value for coal, containing thin beds, or coal of poor quaility, or where information on the thickness and quality of the coal beds is meager or lacking.

Figure 63b. Explanation, distribution by county of remaining resources of bituminous coal in Oklahoma, as of January 1, 1971.

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Thirteen coal beds are workable by strip-mining methods in 15 counties. Almost all of Oklahoma's 2.4 million metric tons (2.6 million tons) of coal production in 1973 was strip-mined. Of the remaining strippable coal resources, 3.9 billion metric tons (4.3 billion tons) (USBM IC 8531, 1971), two-thirds are in the Arkoma Basin and one-third is in the platform area. The weighed average sulfur content of the total remaining resources is 2 percent. The coal beds in the Cherokee Platform area are 0.3 to 1.2 m (1 to 4 ft) thick, dip westward from less than 1 to 2 degrees, and contain more than 3 percent sulfur by weight with the exception of the Croweburg Coal. The coal beds in the Arkoma Basin area are 0.3 to 2.1 m (1 to 7 ft) thick and occur in eroded anticlines and synclines that plunge southwestward. The coals crop out mostly around the sides of these folded and faulted structures, and their dip ranges from near vertical to 3 degrees. Present mines are in beds dipping 3 degrees or less (Keystone Coal Industry Manual, 1975). Important coals are the Iron Post, Croweburg, Mineral, Rowe, Stigler, and McAlester.

Sedimentation Models

Branson (1962) reports that no ideal cyclothem has been found in the Mid-Continent area. One of the few normal well developed cyclothems of the area is given as:

Rock Unit	Waterbearing Properties
shale, dark, unfossiliferous, with concretions	clay-ironstone aquitard
limestone, locally rich in fusulinids	local aquifer where solution voids exist
shale, gray, containing myalinid fossils	aquitard
limestone or clay-ironstone, marginiferids abundant	local aquifer where solution voids exist
shale, black, fissile phosphatic	aquitard
coal	minor aquifer
underclay	aquitard to aquiclude
shale, silty fossil plants	aquitard
sandstone, nonmarine, locally conglomeratic	aquifer, locally important where well sorted and fractured

Few cyclothems display a regional uniformity in the Mid-Continent Area; the Croweburg coal-Verdigris Limestone unit is the best example (Figure 64).

Wanless (1950) has shown the Brenton Cyclothem in its extent from Pennsylvania to Oklahoma and recognized 20-35 distinct cycles in Kansas. Branson (1962) indicates that on the Oklahoma-Kansas Platform there seem to be more than 60 such cycles, 41 marked by at least local coal beds. Where coal beds are missing, the fireclay indicates the coal horizon. Other correlations are possible using the black, fissile, phosphatic, conodont-bearing, radioactive shales. Branson reports these shales as the bases of the Tiawah and Verdigris Limestones (Figure 64); they also comprise the Excello, Anna, Stark, Muncie Creek, and Heebner Shales.

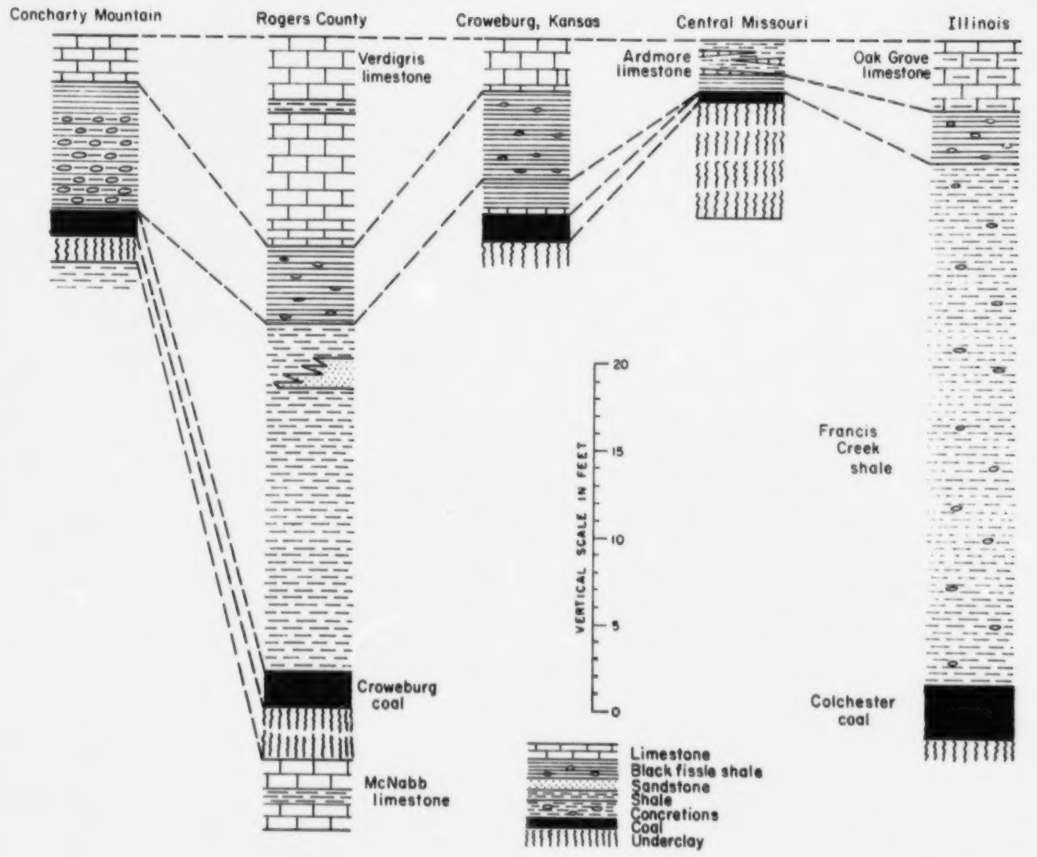
Concharty Mountain
Rogers County
Croweburg, Kansas
Central Missouri
Illinois
Verdigris limestone
Ardmore limestone
Oak Grove limestone
Francis Creek shale
Croweburg coal
McNabb limestone
Colchester coal
VERTICAL SCALE IN FEET
0
5
10
15
20
Limestone
Black fissile shale
Sandstone
Shale
Concretions
Coal
Underclay

Figure 64. Cross-sectional diagram of the Croweburg-Verdigris cyclothem (Branson, 1962).

Occurrence of Limestones

Limestones below the coals (underlines) are few, and those that exist contain marine fossils. Branson (1962) reports that this element of cyclothems is not common in the Mid-Continent Area. More commonly, a cap rock is present over most coal beds. Cap rock is comprised of impure limestone or clay-iron stone. Elsewhere, black fissile shale constitutes the cap rock. It may contain pyritized chonetids and pectinoids.

Fusulinid limestone marks the stage of maximum depth of water, but there are few such limestones in strata other than Virgilian (Table 12).

In the Arkoma Basin, Branson (1962) detects only a crude sort of cyclicity, one that involves sandstone, shale, underclay, coal, and dark shale. An onlap-offlap relationship tends to exist along the margin of the basin. Branson provides a rather detailed picture of the sequence of beds and of their lateral changes; these changes are near the margins of basins within the Mid-Continent Area.

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SECTION 5

CLIMATE OF THE EASTERN COAL PROVINCES

OVERVIEW

This section contains a region-by-region summary of climatic data compiled for the three coal regions that collectively comprise the Eastern Coal Province. The factors that are influenced by and/or influence climate are so numerous and complex that it is beyond the scope of this report to provide a complete description of them. The climatic summary contained in this report addresses only the following major climatic considerations:

1. Temperature
2. Humidity
3. Precipitation
4. Solar Radiation
5. Wind

Climatic factors can generally be considered fixed for a given site. We do not expect that mining of an area appreciably changes the climatic factors within that area.

Planners require an adequate knowledge of the climatic factors for several purposes. Specific climatic considerations for hydrology, water quality management, and mine land planning are provided in other reports. The influence of climatic factors on mine hydrology is discussed in Volume 4; the importance of climatic factors with respect to water quality management is covered in Volume 5; and the relationships between climatic factors and the suitability of the mine site for supporting various types of land uses in the post-mining stages is discussed in Volume 6.

Frequently, the necessary climatic data at a proposed mine site are not available so weather stations are established. However, data collected in the few years between the date when a weather station is established and when reclamation plans are developed are usually too limited to permit any estimation of long-term means or variability. Such variability is demonstrated in Table 13, which shows the monthly precipitation obtained at Mandan, North Dakota for 1973, 1974 and 1975, compared with the 61 year means (Power, 1978).

When short-term on-site data are inadequate, long-term U.S. Weather Bureau records from the nearest recording station in a similar climatic zone are frequently used. However, the distance or relative elevation of the

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TABLE 13. MANDAN, NORTH DAKOTA: DATA FOR MEAN MONTHLY PRECIPITATION (in mm) (Power, 1978)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1973	1	1	3	22	63	18	19	5	56	37	4	12	241
1974	1	5	3	73	84	51	57	38	5	30	4	11	358
1975	9	3	36	162	55	136	17	16	21	18	3	18	494
61-yr	10	10	18	40	55	87	59	42	35	23	13	10	402

nearest station may be too great and thus preclude any meaningful interpretation of the data. It is not unusual to plan mining and reclamation operations without adequate climatic information.

Information about climate is a necessary requirement to the development of sound mining and reclamation plans. Periods of severe cold weather or intense precipitation can bring extraction operations to a halt and set back productivity and delivery schedules unless the conditions have been anticipated and figured into the schedule of operations. Planners need estimates of precipitation volumes and frequencies in order to design drainage and erosion control facilities. Adequate data on seasonal and annual precipitation and temperature provide a basis for a first approximation regarding the adaptability of various plant species and the potential production of these species (Power, 1978).

Glover and others (1978) have discussed the influence of climatic variations on the scheduling of grading operations in the eastern coal regions. Because the soil is vulnerable to erosion during grading activities, those activities should be scheduled to coincide with the periods of low precipitation. The spring and early summer months often have the highest precipitation rates. Therefore, the grading operations especially in critical areas should be scheduled for mid-summer and fall.

In scheduling grading activities, soil stability is another consideration. During the winter months when the ground is frozen, proper compaction cannot usually be obtained. In early spring, the ground is often too wet to be handled properly, and mud can impede the operation of grading equipment.

If there is a choice, it is better to grade during the most favorable time for seeding. From a moisture and temperature point of view, April, May, and June in the spring, and late August, September, and October in the fall, are the best times to seed in West Virginia, Maryland, and Virginia. Seeding during these months will provide uniform emergence and seedling growth.

The continental United States is divided into eleven different climatic zones as illustrated in Figure 65. The Eastern and Interior Coal Regions fall principally into one major climatic zone, Zone 5. This zone is characterized by an intermediate climate, with short cold winters and long hot summers.

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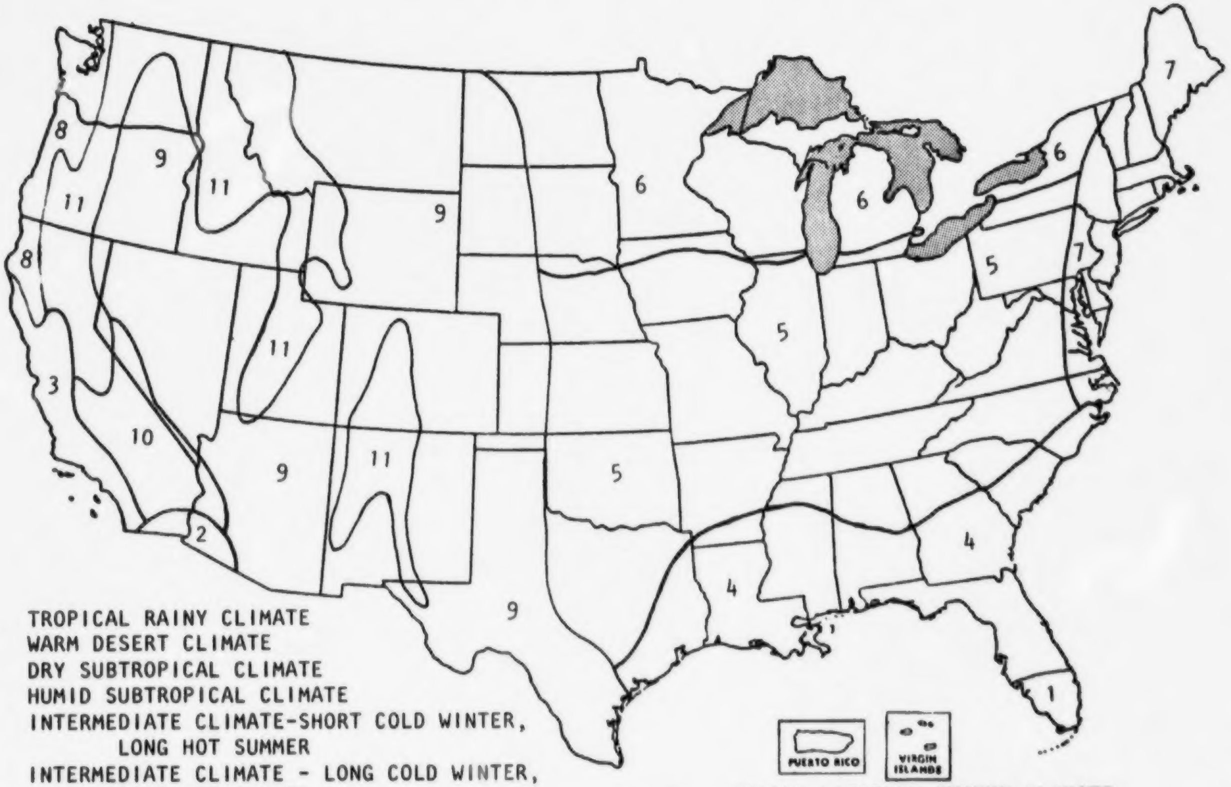

1	TROPICAL RAINY CLIMATE
2	WARM DESERT CLIMATE
3	DRY SUBTROPICAL CLIMATE
4	HUMID SUBTROPICAL CLIMATE
5	INTERMEDIATE CLIMATE-SHORT COLD WINTER, LONG HOT SUMMER
6	INTERMEDIATE CLIMATE - LONG COLD WINTER, SHORT HOT SUMMER
7	MODIFIED HUMID CONTINENTAL CLIMATE
8	WEST COAST MARINE CLIMATE
9	MIDDLE LATITUDE STEPPE CLIMATE
10	MIDDLE LATITUDE DESERT CLIMATE
11	MOUNTAIN CLIMATE

AFTER KOEPPEN, GEIGER, AND OTHERS, ADAPTED FROM BENGTSON AND VAN ROYEN, FUNDAMENTALS OF ECONOMIC GEOGRAPHY, 1935

Figure 65. Climatic regions of the United States (NRPB, 1943).

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The Eastern and Interior Coal Regions also include, although to a much lesser extent, Zones 4, 6, and 7. These zones have the following characteristics:

Zone 4--humid subtropical climate
Zone 6--intermediate climate--long cold winter, short hot summer
Zone 7--modified humid continental climate

A brief summary of the climates of the Appalachian and Interior Coal Basins is provided below. This climatic summary has been adapted mainly from a report that Hittman Associates, Inc. prepared for the Energy Research and Development Administration (Hittman, 1974).

APPALACHIAN REGION

The regional climate is characterized by frequent changes of weather, strongly marked seasons, high humidity and plentiful rainfall. Cold fronts from Canada and low pressure systems from the western Gulf Coast area influence the region's weather. Annual rainfall averages from about 89 cm (35 in.) in the northern portions to over 140 cm (55 in.) in the southern portions with some mountainous areas in this portion receiving 152 to 203 cm (60-80 in.). Although precipitation is fairly well distributed throughout the year, the northern portions receive more precipitation in late spring and during the summer, while the southern portions receive more precipitation during winter and early spring. Serious droughts have occurred locally throughout the region. Snowfall varies annually from more than 254 cm (100 in.) in the higher mountains to less than 8 cm (3 in.) in the southern coastal plain.

Average daily temperatures during January in the northern portions are about 25°F (-4°C) and increase to 45°F (7°C) in the southern provinces. Summer average temperatures are in the 70-80°F (21-27°C) range. Temperatures in the region have reached over 100°F (38°C) and below -20°F (-12°C).

Evaporation from open-water surfaces (class A pan) ranges annually from about 64 cm (25 in.) in the northern portion of the region to about 107 cm (42 in.) in the southern portion (Geraghty, 1973). Potential evapotranspiration annually averages 61 to 92 cm (24 to 36 in.) throughout the region with the exception of two areas, one in West Virginia and south-central Pennsylvania and the other in north-central Pennsylvania and in southwestern New York (Geraghty, 1973).

EASTERN INTERIOR REGION

A continental climate of warm summers and cold winters is experienced in the region, however, winters are less severe in the southern part. The region lies in the path of winter cold waves from Canada and moisture-bearing low pressure systems from the Gulf of Mexico. These air masses supply the region with precipitation, ranging annually from about 92 cm (36 in.) in central Illinois to about 117 cm (46 in.) in western Kentucky. In the northern part of the region, the spring months receive the greatest amount of

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precipitation, while in the southern part, mid-winter and early spring months receive more precipitation. Snowfall ranges from about 61 cm (24 in.) in the northern part to about 25 cm (10 in.) in the southern part.

In January, temperatures in the region average 25°F (-4°C) in the northern part and 35°F (2°C) in the southern part. Summer temperatures average in the upper 70's°F (21°C) throughout the region. Extreme temperatures of 115°F (52°C) and -22°F (- 6 °C) have been experienced at St. Louis on the western edge of the region.

Average annual evaporation from open-water surfaces is about 84 to 97 cm (33 to 38 in.), the higher value occurring in the southern part. Potential evapotranspiration annually averages about 76 cm (30 in.) in the northern part to about 84 cm (33 in.) in the southern part (Geraghty, 1973).

WESTERN INTERIOR REGION

The climate of this region is characterized by hot humid summers and cold humid winters. The annual precipitation ranges from a low of 61 cm (24 in.) along the western and southwestern boundary to more than 147 cm (56 in.) in the Ouachita Mountains of western Arkansas. The majority of the area receives between 81 and 122 cm (32 and 48 in.) of precipitation per year. March, April, May and June are the months with the highest precipitation. Parts of the area receive over 10 cm (4 in.) per month during this time. The rains come during the growing season. Fall rains in this province may average over 5 cm (2 in.) per month. The humidity averages between 60 and 70 percent most of the year, with some portions having a higher average in the fall and winter.

Temperatures in the southern portion average above 40°F (4°C) in January and above 80°F (27°C) in July. In the northern portion, the temperatures in January average above 20°F (-7°C) and above 70°F (21°C) in July. The winds are typically out of the west and northwest in the winter and out of the south the rest of the year. This area is subject to many tornadoes every year.

SECTION 6

WATER RESOURCES OF THE EASTERN COAL PROVINCES

OVERVIEW

This section provides a broad, region-by-region summary of the existing water resources of the Eastern Coal Provinces. It also includes an introduction to the major classifications of water resource areas in the United States. In the region-by-region summary, which conforms to the existing systems of classification, the existing water resources under the general groupings of surface and ground water resources are discussed. For each grouping, information is provided with respect to the quantity and quality of available resources as well as present levels and patterns of use.

Knowledge of the existing water resources at a given site is essential in order that planners may adequately evaluate the potential impact of the mining operation on this resource. Such knowledge is also a prerequisite to formulating adequate control strategies during both the extraction and reclamation phases of the operations.

The importance of water resources in the planning of surface coal mining operations is indicated by extensive coverage of this topic in the various volumes of the User's Manual. In Volume 4, Mine Hydrology, the authors provide a detailed discussion of the basic hydrological elements that can be affected by surface mining operations and that must be considered during the planning stages. Volume 4 contains many of the basic hydrogeological and geochemical concepts regarding the occurrence and movement of groundwater within soil and bedrock strata of the mineable coal beds in the eastern United States. In Volume 4, selected basic concepts that planners must consider are reviewed. These concepts include: the definition of premining and postmining groundwater flow systems, the data required for such analysis, methods for collecting the data, basic approaches to these analyses, and so forth.

In Volume 5, Mine Drainage Management and Monitoring, the authors provide the technical background necessary to establish pragmatic guidelines for making decisions about water quality management in surface mining. Four major areas of concentration are identified. The first area includes mine drainage control and the nature of coal mine water. In the second area, drainage abatement techniques commonly used in surface mining are summarized. In the third area, the authors discuss a number of experimental techniques currently under consideration because they are methods that have some potential for

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controlling mine drainage. In the fourth and final area, various aspects and considerations associated with monitoring programs are discussed.

The materials presented in this section are intended to provide a general overview of water resource conditions as they exist in the study region. This overview can serve as a point of reference for the more detailed treatment of water resources provided by other reports.

CLASSIFICATION OF WATER RESOURCE AREAS

The two major groupings of water resource areas in common use in the United States are surface and groundwater. The first grouping was developed principally for surface water resources and consists of the 15 major drainage basins. The Federal Water Pollution Control Administration collected water pollution data from these drainage basins. The geographic location of these basins is illustrated in Figure 11 and discussed in Section 3 of this report. The Eastern Coal Provinces therefore encompass the following seven major river basins:

1. North Atlantic
2. Southeast
3. Tennessee River
4. Ohio River
5. Upper Mississippi
6. Missouri River
7. Southwest-Lower Mississippi

The second grouping is used for groundwater resources. This grouping, developed by Thomas (1952), divides the conterminous United States into ten groundwater regions, which are represented in Figure 66 (Walton, 1970). The Eastern Coal Provinces occur in four of these ten regions, namely: the Glaciated Central Region, the Unglaciated Central Region, the Unglaciated Appalachian Region, and the Coastal Plain Region. Walton (1970) has summarized groundwater conditions in these regions; his summary is reproduced below. This summary is followed by a detailed review of water resource availability in the three coal provinces covered by this report. These latter data have been abstracted and summarized from a combination of published and unpublished background data prepared by Hittman Associates for the Energy Research and Development Administration (Hittman, 1974).

GROUNDWATER CONDITIONS

Unglaciated Central Region

The Unglaciated Central Region extends from the Great Plains or Rocky Mountains on the west to the Appalachian Mountains on the east, north of the Gulf Coastal plain and south of the glaciated area, as shown in Figure 67. It includes the driftless area of Wisconsin and a large part of the Missouri River Basin in Montana, Wyoming, and the Dakotas. The region almost pinches out in Nebraska and in southern Illinois; it broadens in the Arkansas and Red

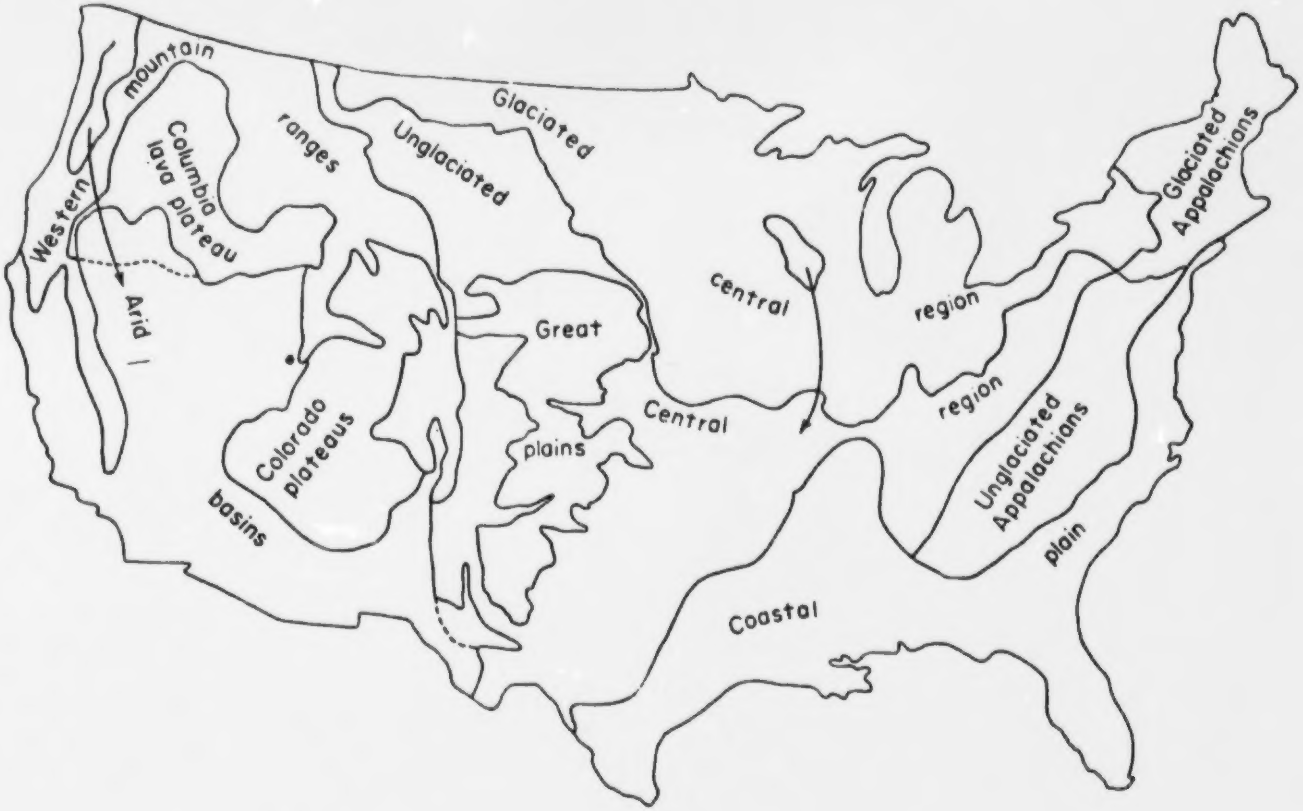
Western
mountain
ranges
Columbia
lava plateau
Arid
basins
Colorado
plateaus
Glaciated
Unglaciated
Great
plains
central
Central
region
region
Glaciated
Appalachians
Unglaciated
Appalachians
Coastal
plain

Figure 66. Groundwater regions of the counterminous United States developed by Thomas (1952) (Walton, 1970).

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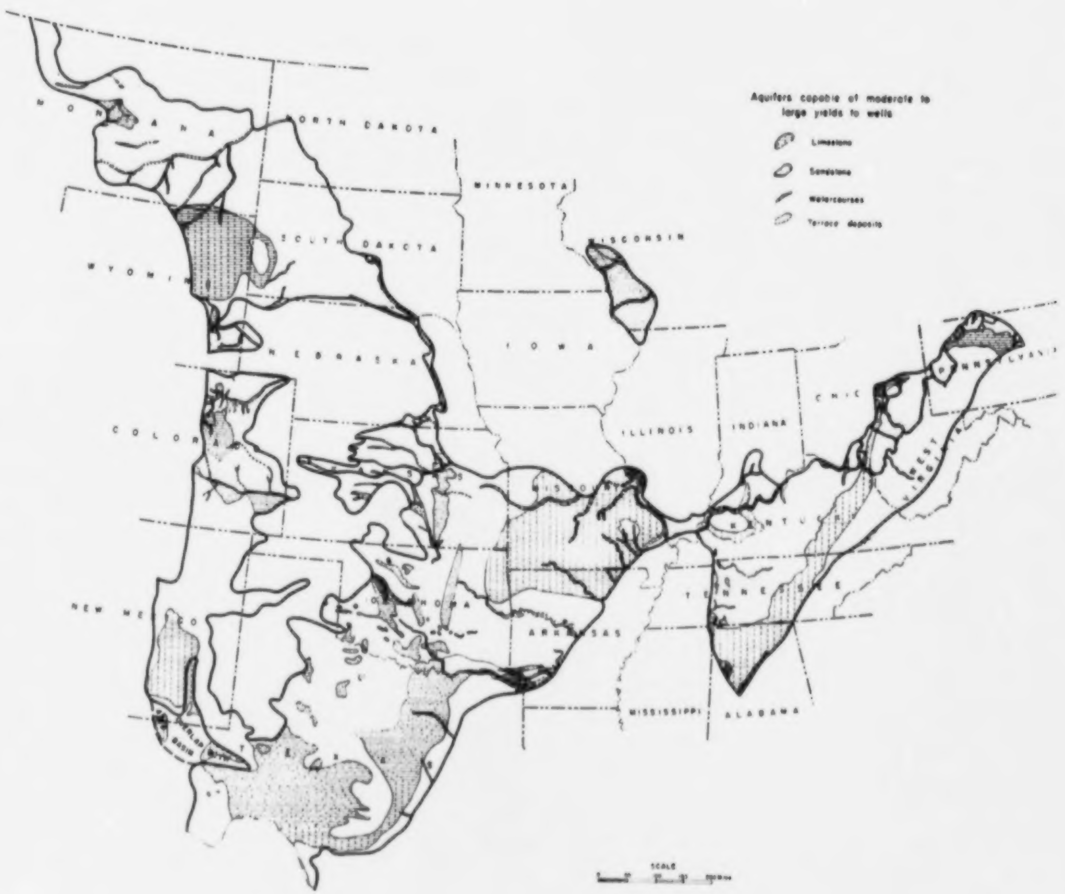
Aquifers capable of moderate to large yields to wells
Limestone
Sandstone
Watercourses
Terrace deposits
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
WYOMING
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
WEST VIRGINIA
COLORADO
KANSAS
MISSOURI
KENTUCKY
TENNESSEE
NEW MEXICO
OKLAHOMA
ARKANSAS
MISSISSIPPI
ALABAMA
TEXAS
SCALE

Figure 67. Groundwater conditions as described by Thomas (1952) in Unglaciated Central Region (Walton, 1970).

River Basins and farther east to include much of the Ohio and Tennessee River Basins. The region also extends into Pennsylvania and New York. The region has rocks that range in age from Precambrian to Recent, and it includes some ancient mountain ranges.

All the extensive aquifers are consolidated sedimentary rocks with sediments that are generally in flat-lying beds but are steeply inclined in limited areas. Sand and gravel aquifers are restricted to the valleys of streams and are greatly limited in areal extent. Watercourses contain the most productive sand and gravel aquifers. The region includes sedimentary rocks ranging in age from Cambrian to Tertiary: conglomerate, sandstone, siltstone, shale, clay, coal, chert, marl, limestone, dolomite and gypsum. The rocks vary greatly in permeability. In general, the relatively impermeable rocks, clays, and shales, all yield supplies sufficient only for domestic or stock use. These supplies come from joints and zones of brittle shale where weathering and fracturing have developed some interstices.

Limestone is the most productive and extensive consolidated rock aquifer in the region. Important limestone aquifers are found in the Roswell Basin in New Mexico; the Edwards Plateau in Texas; the Ozark area in Missouri, Arkansas, Oklahoma, and Kansas; the Black Hills area in South Dakota and Wyoming; and the Tennessee Valley in Tennessee and Alabama.

Sandstones are also important consolidated rock aquifers; the Dakota Sandstone is a well known deep artesian aquifer of the Dakotas and several other states. Other sandstone aquifers occur in parts of Texas, Oklahoma, Kansas, Colorado, Wisconsin, Pennsylvania, and Ohio. Many of the consolidated rock aquifers in the region contain water that is too highly mineralized for use. Most sedimentary rocks are of marine origin and in places they contain fresh water only within a few hundred feet of the surface.

The sand and gravel of stream valleys has a relatively small volume but may be highly productive, especially when combined with recharge by induced infiltration of surface water in streams. Most alluvium yields sufficient amounts of water for domestic or stock use; aquifers capable of yielding large quantities of water constitute only a minor proportion of the total alluvium in most stream valleys. Sand and gravel have accumulated in considerable quantities near the north boundary of the unglaciated region as glacial outwash. In many valleys the outwash is also found beyond the limit of glaciation. Some sand and gravel beds deposited by ancient streams form terraces above present stream channels. Terrace deposits constitute important aquifers in Oklahoma and Texas.

Glaciated Central Region

The Glaciated Central Region includes the glaciated part of the central lowland, extending from the Canadian border southward to approximately the present channel of the Missouri River from Great Falls to St. Louis and that of the Ohio River from Pittsburgh to its mouth as shown in Figure 68. The preglacial surface was formed on consolidated sedimentary rocks including sandstones and limestones. Several of the rocks beneath the glacial drift form important aquifers.

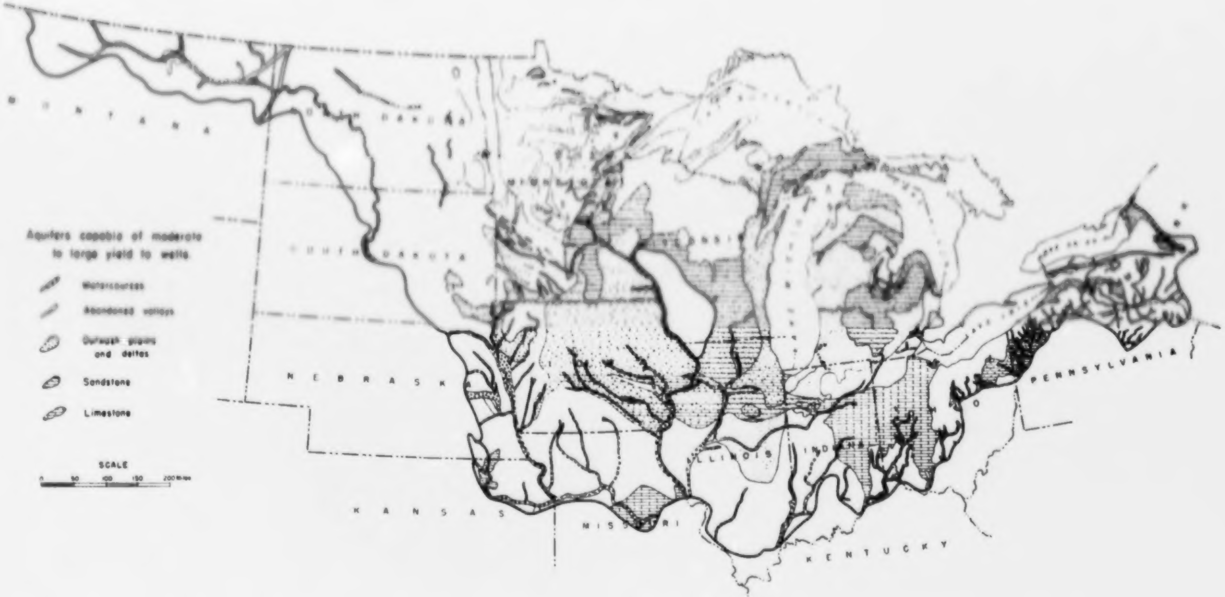
Aquifers capable of moderate to large yield to wells
Watercourses
Abandoned valleys
Outwash plains and deltas
Sandstone
Limestone
SCALE
0 50 100 150 200 Miles
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
MISSOURI
ILLINOIS
INDIANA
KENTUCKY
PENNSYLVANIA

Figure 68. Groundwater conditions as reported by Thomas (1952) in Glaciated Central Region (Walton, 1970).

The Dakota Sandstone extends into Minnesota, Iowa, Montana, and Nebraska. Sandstone aquifers extend also through large parts of Iowa, eastern Minnesota, Wisconsin, northern Illinois, and Michigan. These aquifers are deeply buried in places, and water is confined in them under artesian pressure. Limestones are important sources of water in some areas. The limestone contains permeable zones in the coral reefs or along joints and fractures. In the vicinity of Lake Superior, sedimentary rocks are absent and crystalline or metamorphic rocks crop out or are buried beneath glacial drift. The yields of these rocks are generally sufficient only for domestic and stock use except along faults and fracture zones.

The glacial drift is very thin in some places and hundreds of feet thick in others; it is thickest in the southern peninsula of Michigan and the adjacent northern three-fifths of Indiana, and nearly as thick in western Ohio, northeastern Illinois, northcentral Iowa, eastern and northern Wisconsin, and a substantial part of Minnesota. The bulk of the glacial drift is till, deposited directly by the melting ice, and entirely unsorted. Where the till is composed chiefly of clay-size particles, it is relatively impermeable; in places, the till is composed chiefly of sandy material and is fairly permeable. All ranges from clay-till to sandy to gravelly till occur in the region.

The sand and gravel deposits of streams that issued from the ice occur in abundant irregular lenses and stringers that are intermingled with the till. The deposits also occur in deltas formed in glacial lakes, in outwash aprons, and in valley trains. The sand and gravel intermingled with the till yield moderate to small water supplies. The sediments deposited in glacial lakes are predominantly of fine texture; however, sandy deposits are found near shorelines. The outwash aprons are generally well sorted sand and gravel deposits having large areal extents and large yields.

The valley-train deposits of sand and gravel, which occupy watercourses of present streams and valleys no longer occupied by streams, are the aquifers that produce the greatest quantities of water. The valley trains extend for many miles from the ice front and many go beyond the limits of the glaciated region. Many of the cities in the glaciated region and adjacent parts of the unglaciated region are along watercourses where sand and gravel beds yield large quantities of water to wells. Sand and gravel deposits in valleys that were occupied by rivers draining the ice sheet but have since been abandoned by their streams yield moderate to large supplies of water. In substantial areas where the glacial drift is not productive, the bedrock is capable of furnishing moderate quantities of water to wells.

Unglaciated Appalachian Region

The Unglaciated Appalachian Region covers the unglaciated parts of the Appalachian Valley and Piedmont Provinces and includes parts of Alabama, Georgia, Tennessee, South and North Carolina, Virginia, Maryland, Delaware, Pennsylvania, and New Jersey as shown in Figure 69.

The dominant bedrocks are crystalline or metamorphic or well consolidated sedimentary rocks. These rocks, including chiefly granite, gneiss, and schist, are the principal aquifers of the region; water occurs in joints and fractures, which either occur in the fresh rock to considerable depths or

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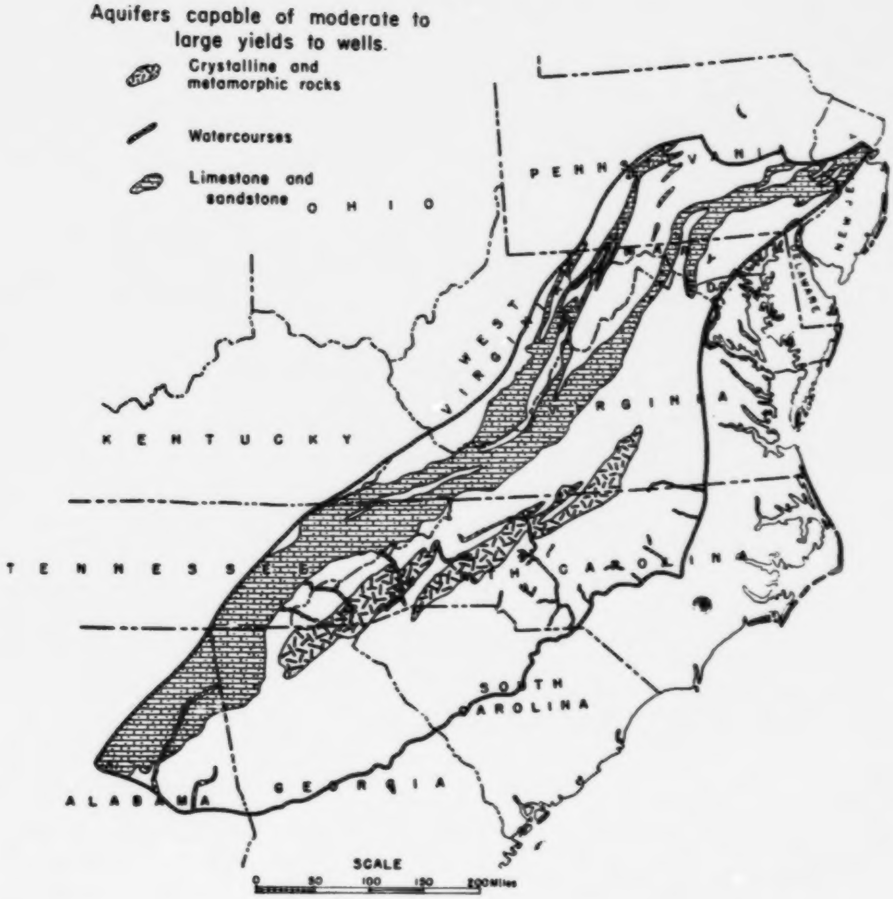
Aquifers capable of moderate to large yields to wells.
Crystalline and metamorphic rocks
Watercourses
Limestone and sandstone
OHIO
PENNSYLVANIA
WEST VIRGINIA
VIRGINIA
KENTUCKY
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
SCALE
0 50 100 150 200 Miles

Figure 69. Groundwater conditions reported by Thomas (1952) in Unglaciated Appalachian Region (Walton, 1970).

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occur in the surficial materials that are unconsolidated and weathered. Some limestones contain large and extensive solution cavities and channels. These rocks furnish water for practically all the domestic supplies and many of the small industrial and public supplies.

Topography and rock type are important guides to the productivities of wells. Granitic rocks commonly have parting planes usually parallel to the rock surface on hills and in valleys. Wells in sheeted granitic terranes usually have higher yields on the lowlands than on uplands. Interstices are most abundant near the surface and little water is obtained at depths greater than a few hundred feet.

Gneiss produces some water particularly in North and South Carolina; schist is generally the least permeable of the crystalline rocks. Metamorphic and sedimentary rocks yield water chiefly from fractures. Sandstones are important aquifers in New Jersey and eastern Pennsylvania. Limestones and dolomites yield moderate to large quantities of water in many parts of the region. For large quantities of water, the best prospects are the sand and gravel deposits in the alluvium of streams. Many watercourses contain sand and gravel aquifers.

Atlantic and Gulf Coastal Plain Region

The Atlantic and Gulf Coastal Plain Region extends from Long Island and the sandy islands and capes of Massachusetts to Texas and includes the Mississippi Embayment as far north as Cairo, Illinois, as shown in Figure 70. Most of the region is underlain by a thick succession of loose or semiconsolidated sediments that dip gently seaward. Sand and gravel aquifers, which are interbedded with less permeable argillaceous deposits, occur in the sediments. The most heavily developed sand and gravel aquifers are in eastern Arkansas, southwestern Louisiana, and southeastern Texas; the Houston-Galveston and Baltimore, Maryland, areas are other areas of intensive pumping.

Some areas have had difficulties with salt-water encroachment. Limestones in Florida and southeast Georgia are very permeable aquifers. Glacial outwash deposits are the most important aquifers of Long Island. The sediments of the watercourses are generally of fine texture, and permeable sand and gravel aquifers are rare.

The region is a huge, seaward-thickening wedge of generally unconsolidated, but locally consolidated, sedimentary rocks lying on Precambrian, Paleozoic, and Mesozoic bedrocks. The sediments are mainly clay, silt, sand, gravel, marl, and limestone in alternating and intertonguing strata. The thicknesses of the deposits vary from as little as a few hundred feet in places in the northeasternmost part of the region to tens of thousands of feet in the general vicinity of the mouth of the Mississippi River.

This region, especially the southern part of it, contains some of the most extensive and productive aquifers in the conterminous United States. Only a broad strip running northeastward through Texas into Louisiana is underlain by relatively impermeable rocks of Tertiary age; a smaller crescent

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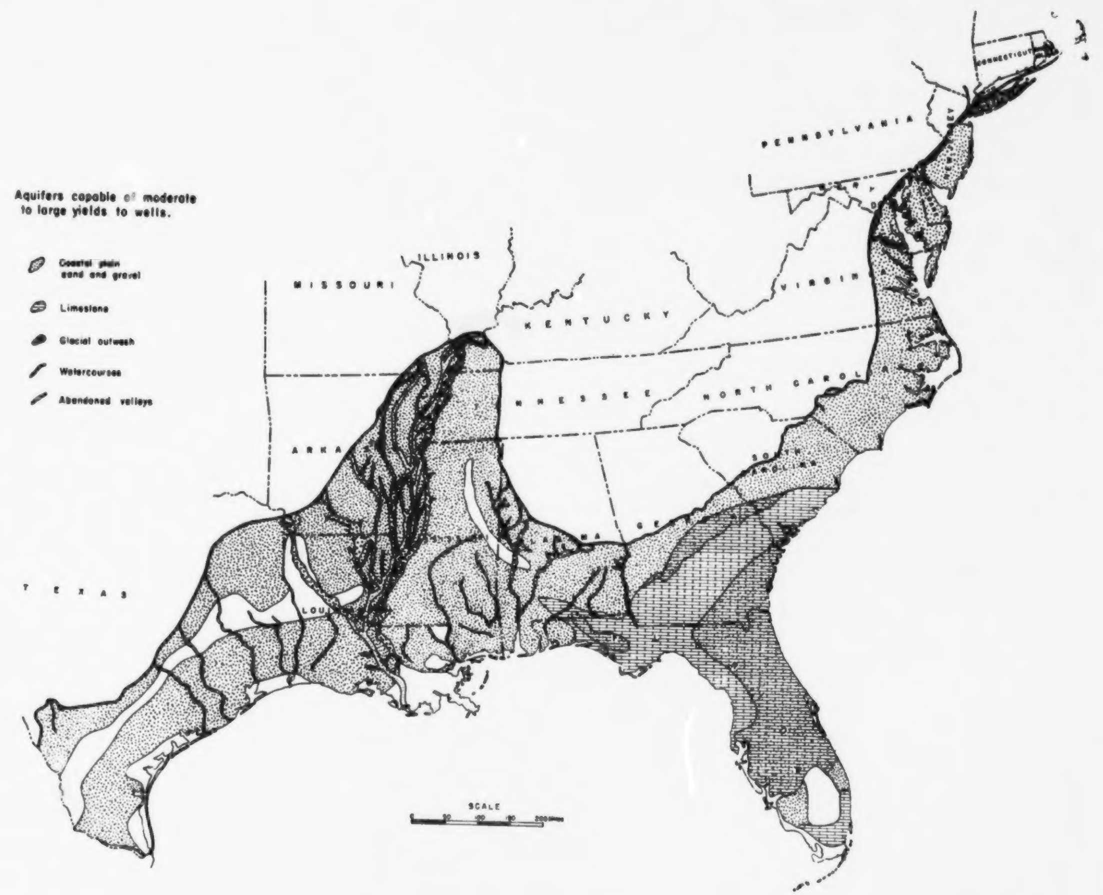
Aquifers capable of moderate to large yields to wells.
▨ Coastal plain sand and gravel
▤ Limestone
● Glacial outwash
Watercourses
Abandoned valleys
PENNSYLVANIA
CONNECTICUT
ILLINOIS
MISSOURI
KENTUCKY
VIRGIN
NORTH CAROLINA
NNESSEE
ARKA
SOUTH CAROLINA
GE
TEXAS
LOU
SCALE
0
50
100
150
200 Miles

Figure 70. Groundwater conditions reported by Thomas (1952) in the Atlantic and Gulf Coastal Plain Regions (Walton, 1970).

TABLE 14. RESERVOIR STORAGE FOR THE APPALACHIAN REGION
(Sources: COE, 1969; Pierce, 1972)

Basin	Flood control (ac-ft)	Water supply (ac-ft)	Conservation, recreation, wildlife, etc. (ac-ft)
Allegheny	1,626,100	-	-
Monongahela	429,000	-	341,770
Beaver	496,900	61,075	-
Muskingum	1,588,800	42,000	-
Little Kanawha	-	-	-
Hocking	17,600	5,800	3,500
Kanawha	1,252,100	-	193,500
Guyandotte	-	-	-
Big Sandy	289,449	-	125,204
Ohio	Several navigational structures on main stem		
Scioto	-	-	-
Licking	443,700	-	83,900
Kentucky	202,500	-	25,250
Cumberland	-	-	446,000
Black Warrior	280,600	30,300	394,300
Coosa	245,300	-	67,600

Cubic meters = acre - feet x 1233.4

TABLE 15. RUNOFF CHARACTERISTICS OF SELECTED RIVERS IN THE APPALACHIAN REGION
(Sources: Geraghty, 1973; USGS, 1970a; Pierce, 1972; COE, 1969)

River	Average discharge (cfs)	Maximum instantaneous discharge (cfs)	Minimum daily discharge (cfs)	7 day average 1 in 10 yr. low flow (cfs)	1 day in 30 yrs. low flow (cfs)
Pennsylvania					
Susquehanna River at Harrisburg	34,000	52,607	16,920		
Allegheny River at Natrona	19,490	238,000	922	1,096	732
Monongahela River at Greensboro	8,168	140,000	204	384	208
Beaver at Wampum	2,365	50,106	74	232	-
Ohio					
Ohio River at Sewickley	32,740	574,000	1,800	2,370	-
Muskingum River at McConnelsville	7,282	126,000	218	565	397
Kentucky					-
Big Sandy River at Louisa	4,228	89,400	1,510	59	29
Kentucky River at Winchester	5,223	92,400	10(est)	33	-
Cumberland at Rowena	8,867	162,000	0	325	28.5
West Virginia					
Kanawha River at Charleston	10,367	216,000	1,030	1,200	880
Ohio River at Parkersburg	50,730	440,000	2,290	3,590	-
Guyandotte at Branchland	1,573	40,400	3.6	20	10.3
Virginia					
New River (Kanawha) at Glenlyn	4,929	226,000	770	1,050	735
Maryland					
North Branch Potomac River at Cumberland	1,264	1,650	640	41	-
Alabama					
Black Warrior River at Tuscaloosa	7,640	224,000	37	92	51
Coosa River at Gadsden	9,264	76,900	100	1,430	840

Cubic meters per second = cubic feet per second x 0.028

shaped strip in Mississippi and Alabama and small scattered areas in Texas, Louisiana, and Florida are underlain by aquifers in which all the groundwater is saline.

There is a very wide range in the number and depth of permeable sand and gravel beds in the sediments. There is also a wide variation in the extent to which different beds have been flushed of salt water. Some of the beds are thick and extend over hundreds or thousands of square miles; other beds are thin and small in areal extent; these beds intertongue complexly with other beds of different kinds.

APPALACHIAN REGION

Water is abundant in the Appalachian Region. Streamflow from the region is more than 568.5 million cu m (150 billion gal) daily (COE, 1969). Groundwater, in small to moderate amounts, is available nearly everywhere and in some areas groundwater is available in abundant quantities. In general, water quality in the region is good; however, municipal and industrial wastes and acid mine drainage have caused water quality problems in parts of the region.

Water resources of the region are intensively developed. Existing surface water reservoirs, described in Table 14, can store about 51.66 billion cu m (42 million acre-ft) or one-fourth of the total average streamflow. Extensive plans have been prepared for the development of water resources at the regional and river basin levels as well as at the state and local levels (COE, 1969; ORBCC, 1968).

Surface Water

Two-thirds of the flow originating in the region is carried in four major river systems: Ohio, Tennessee, Susquehanna, and Alabama. In the counties that have the highest concentration of coal reserves, the Ohio River Basin in the states of Pennsylvania, Ohio, West Virginia and Virginia and the Black Warrior and Coosa River Basins in Alabama account for the major amounts of streamflow. Many large rivers and tributaries comprise these major systems. Runoff characteristics of the major rivers in the region are presented in Table 15 which is based on data reported by Geraghty (1973); USGS (1970a); and Pierce (1972).

Figure 71 shows the average annual runoff for the Appalachian Region. According to Meyer (1965), runoff rates for this region are among the highest in the country. Streamflow is variable from year-to-year, with 1931 being noted for large deficiencies, about half the average, over most of the region (Meyer, 1965). Streams throughout the region experience high flows during spring and low flows during summer.

Quality of surface water in the region varies depending on climate, rock types and degree of weathering, flow conditions, and changes in water and land use patterns. In about 90 percent of the region, the prevalent concentrations

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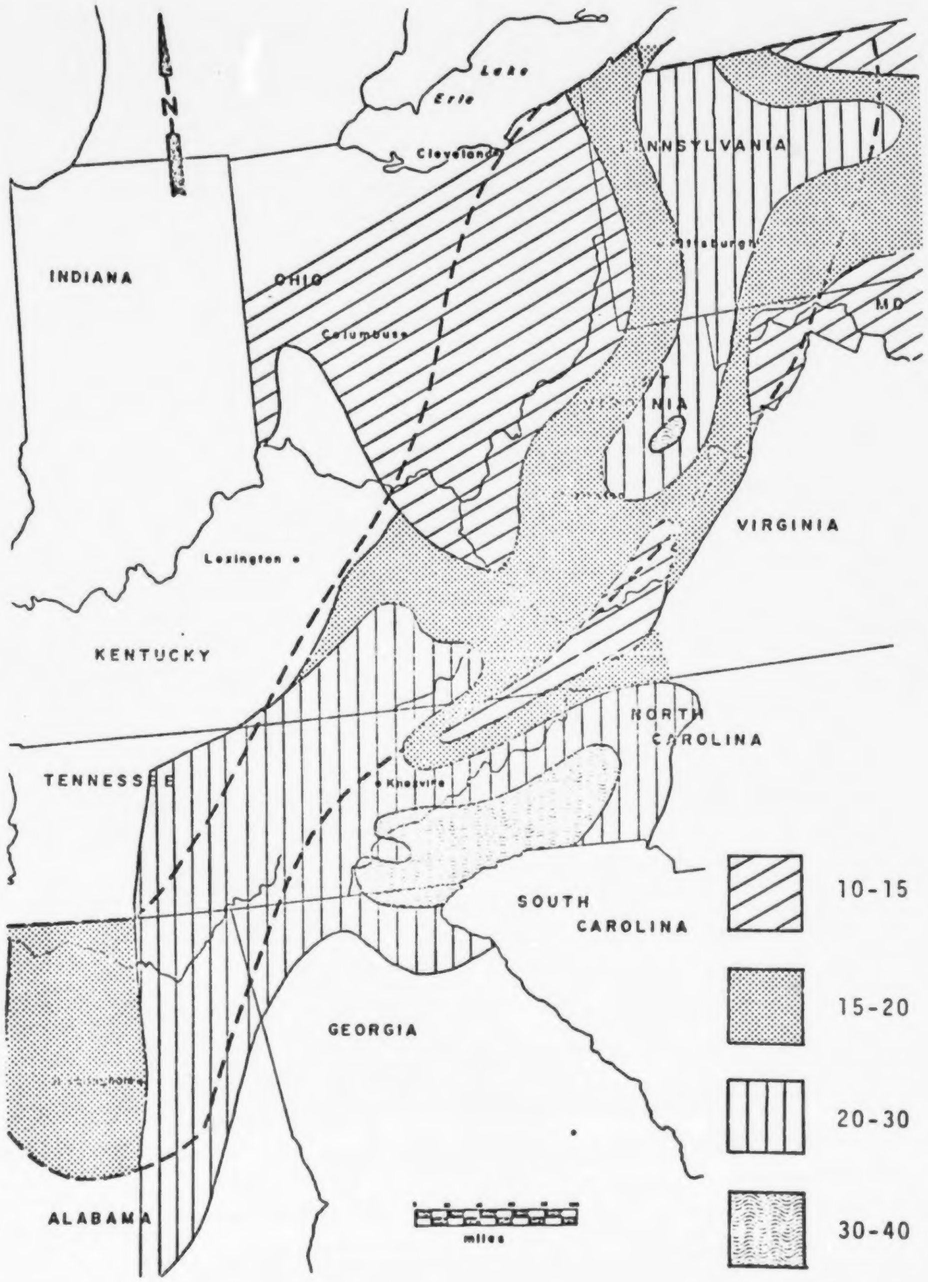
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TENNESSEE
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Figure 71. Average annual runoff (inches) in the Appalachian Region (ORBCC, 1968; Pierce, 1972).

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of dissolved solids are less than 300 ppm (parts per million); however, depending on the chemical type of stream (see below) values greater than 5,000 ppm may be observed. Chemical types, associated proportionate areas of the region, and average total dissolved solids, as reported by Collier and Whetstone (Meyer, 1965), are presented below:

Type	Area (percent)	Total dissolved solids (ppm)
(1) Mixed	23	50
(2) Calcium-magnesium bicarbonate	42	50-300
(3) Calcium sulfate		
natural	20	150
affected by mine drainage	13	100-2,000
(4) Sodium chloride affected by brines	2	5,000

Existing water uses include municipal, industrial, agricultural, mining, and thermal power. Estimated water use for selected counties that have the highest concentration of coal resources is presented in Table 16. During 1970, an estimated 41.77 million cu m per day (11,021 mgd) were used for municipal and industrial purposes in the selected counties. Of the total municipal and industrial water use in the basins, the selected counties accounted for about 83 percent.

Many of the states in the region adhere to the riparian concept of surface water rights. This is administered at the state level. Many states have adopted the rule of "reasonable use;" this rule allows water utilization that is consistent with like uses by other riparian owners.

Compacts limiting the use of water between states have only been made by the Tennessee Valley Authority (TVA), which is a federal agency with responsibilities of flood control, power and navigation development in the Tennessee River Basin. Some compacts have been made between states to develop the water resources of a mutual river basin, for example, Tombigbee-Tennessee Waterway Development Compact between Alabama and Mississippi. These compacts do not limit water use within a particular state.

Groundwater

Major aquifers (water-yielding units) in the region are the unconsolidated alluvial deposits, which are usually located along major rivers. In some instances these deposits are of glacial origin and are located in the highly cavernous carbonate rocks of the Valley and Ridge and western Appalachian Plateau Provinces (Meyer, 1965). Alluvium may yield from 6 to more than 189 liters per second (100 to more than 3,000 gpm) to an individual well; carbonate areas may yield from 3 to more than 126 liters per second (50 to more than 2,000 gpm) to an individual well. Additionally, large quantities of groundwater probably occur locally in a northeast-southwest trending belt of coarse clastic rocks of Pennsylvanian age in the eastern part of the Appalachian Plateau Province, although much of that area is untested. Local yeilds in this area may be 6 liters per second (100 gpm)

TABLE 16. ESTIMATED WATER USE FOR SELECTED COUNTIES IN THE APPALACHIAN REGION (Source: COE, 1969)

River basin	1970 municipal use (mgd)	% of 1960 municipal population supplied by groundwater	1970 industrial use (mgd)	Total 1970 municipal & industrial water use in river basin (mgd)	% of 1970 total basin water use in the selected counties
Pennsylvania					
Susquehanna	4.9	N.A.	0.4	344*	1.5
Allegheny	200.2	6.7	203.4	576.3	70.0
Monongahela	117.3	3.3	5119.1	5,301.9	98.8
Beaver	26.3	10.2	141.6	1,194.1	14.1
Ohio (Upper)	32.0	80.1	243.9	790.9	34.9
Ohio					
Muskingum	61.6	75.3	46.4	123.1	87.7
Beaver	13.4	45.8	751.7	1,194.1	64.0
Ohio (Upper)	43.0	50.6	202.0	790.9	31.0
Kentucky					
Big Sandy	8.9	23.2	1.4	73.3	14.1
Kentucky	2.1	44.0	0	37.2	5.6
Cumberland	3.2	30.5	1.7	155.1	3.2
West Virginia					
Kanawha	34.4	18.8	1674.5	1,833.0	93.2
Ohio (Upper)	19.2	37.6	166.9	790.9	23.5
Monongahela	26.9	6.3	23.1	5,301.9	0.9
Gyandotte	4.6	54.5	0.3	5.1	96.1
Big Sandy	5.8	69.8	0.1	73.3	8.0
North Branch Potomac	.8	54.5+	0.04	272.3	0.3

Cubic meters per day = million gallons per day x 3785

(Continued)

TABLE 16. (Continued)

River basin	1970 municipal use (mgd)	% of 1960 municipal population supplied by groundwater	1970 industrial use (mgd)	Total 1970 municipal & industrial water use in river basin (mgd)	% of 1970 total basin water use in the selected counties
Virginia					
Kanawha	1.1	10.0	0.2	1,833.0	0.1
Big Sandy	0.7	86.3	0	73.3	0.9
Tennessee					
Cumberland	0.2	0	0	155.1	0.1
Maryland					
North Branch Potomac	20.9	3.3[+]	250.0	272.3	99.5
Monongahela	0.6	60.3	0.1	5,301.9	0.01
Alabama					
Black Warrior	148.3	29.4[‡]	505.7	1,026.9	63.7
Coosa	1.2	99.4[‡]	865.4	1,285.6	75.2
Tombigbee	6.2	9.1[‡]	20.5	201.7	13.2
Cahaba	12.5	7.0[‡]	7.2	63.1	31.2

* Does not include self-supplied industrial water.
+ Based on estimated water use.
‡ Based on 1970 water use data.

N.A. - not available

Cubic meters per day = million gallons per day x 3785 or more. Throughout the rest of the region, the yields to wells that are in dense, sparsely fractured, crystalline rock generally range from 0.2 to 1.6 liters per second (3 to 25 gpm).

In most instances, the quality of the groundwater is satisfactory for domestic and other uses; however, there are some problems. In certain areas, where there is iron or hardness, the groundwater may require extra treatment before it can be used. Saline water occurs at depths of several hundred feet in the western part of the Appalachian Plateau Province. Table 17 contains the characteristics of groundwater quality for unconsolidated deposits; Table 18 contains comparable data for consolidated aquifers.

Throughout the region, many municipalities, industries, and rural homes use groundwater extensively. In many river basins, more than 50 percent of the municipal water supply is obtained from groundwater. Groundwater will continue to be a catalyst to economic growth in many parts of the region.

EASTERN INTERIOR REGION

Water resources of the Eastern Interior Region are presently adequate for consumption by the population. Existing knowledge reveals that groundwater resources are large in some areas; however, in some of these areas groundwater is heavily utilized. Water quality problems occur in parts of the region as a result of the discharge of treated municipal and industrial wastes and acid mine drainage.

Surface Water

Runoff from the region is carried by tributaries to the main stem Mississippi and Ohio Rivers. In Illinois, the Rock, Illinois, Kaskaskia, and Big Muddy Rivers contribute about 30 percent of the runoff in the Upper Mississippi River Basin. The Wabash and White Rivers in Indiana and the Green, Pond, and Tradewater Rivers in Kentucky supply about 30 percent of the streamflow to the Ohio River. Runoff characteristics of the major rivers are presented in Table 19.

The months of highest runoff are generally March through June in the northern part of the region and January through April in the southern part (ORBCC, 1968; UMRBCC, 1970). During the spring, melting snow augments streamflow in the northern part of the region, while in the southern part, annual precipitation is more evenly distributed and temperatures are more moderate; these conditions contribute to the higher winter and early spring flows. Average annual runoff ranges from about 20 cm (8 in.) in the northern part of the region to about 38 cm (15 in.) in the southern part (Geraghty, 1973; UMRBCC, 1970).

Depending on flow, water quality of the streams and rivers is highly variable. Hardness is a problem, ranging from hard to very hard in the

TABLE 17. GROUNDWATER QUALITY OF UNCONSOLIDATED DEPOSITS IN THE APPALACHIAN REGION (Source: ORBCC, 1968)*

Source	Well depths (m) (ft)	Depths to water (m) (ft)	Hardness (mg/1)	Sulfate (mg/1)	Chloride (mg/1)	Iron (mg/1)	Total dissolved solids (mg/1)
Sand and gravel of Ohio River valley-fill deposits	18-31 (60-100)	9-15 (30-50)	130-400	50-200	20-60	0.1-3.0	250-650
Allegheny River glacial and alluvial sediments	11-76 (35-250)	3-9 (10-30)	120-280	15-350	30-90	0-3.0	180-600
Muskingum River valley	12-76 (40-250)	---	250-900	---	0-800	0.0-8.0	330-1000
Kanawha River alluvium	15-40 (50-130)	---	20-650	---	5-380	2-50	---
Little Kanawha River alluvium	---	---	---	---	---	---	---
Glacial and alluvial sand and gravel in the Ohio River valley	24-49 (80-160)	---	250-350	20-70	5-20	0.01-0.2	300-450
Monongahela River alluvium	15-40 (50-130)	5-10 (15-34)	120-1700	50-1700	20-350	1-120	300-3000

* Typical values--this table does not include unusually high or low values.

TABLE 18. GROUNDWATER QUALITY OF CONSOLIDATED AQUIFERS IN THE APPALACHIAN REGION* (Source: ORBCC, 1968)

Source	Well depths (m) (ft)	Depths to water (m) (ft)	Hardness (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Iron (mg/l)	Total dissolved solids (mg/l)
Limestones of Mississippian System in Headwater Area of Cumberland River	18-31 (60-100)	6-15 (20-50)	50-200	10-50	2-20	.2-5	200-400
Pottsville Formation - Allegheny Basin	4-122 (14-400)	3-20 (10-65)	50-150	3-160	1-130	.05-19	74-570
Allegheny Formation - Allegheny Basin	18-107 (60-350)	---	91-250	6-100	1-61	.03-8.9	38-400
Sandstones and conglomerates of Pottsville and Allegheny Formations in Big Sandy-Guyandotte Headwater Area	34-122 (110-400)	---	50-400	30-350	10-50	---	---
Allegheny Formation (sandstone) Kanawha Basin	12-91 (40-300)	---	10-190	---	3.0-1000	0.1-7.0	120-1000
Pottsville Formation (sandstone) Kanawha Basin	8-107 (25-350)	---	20-930	---	1.5-1000	0.0-38	---
Pottsville and Allegheny Formations Monongahela Basin	31-152 (100-500) 122-355 (400-1100)	0-46 (0-150) 15-152 (50-500)	20-100	1-30	1-30	0.3-6	50-250

* Typical values--this table does not include unusually high or low values.

TABLE 19. RUNOFF CHARACTERISTICS OF SELECTED RIVERS IN THE EASTERN INTERIOR REGION (Sources: ORBCC, 1968; UMRBCC, 1970)

River	Average discharge (cfs)	Maximum discharge (cfs)	Minimum discharge (cfs)	7 day average 1 in 10 yrs. (cfs)	1 day in 30 yrs. (cfs)
Illinois					
Rock River near Joslin	5,237	46,200	834	1,110	825
Illinois River at Marseilles	10,710	93,900	1,460	3,150	1,200
Illinois River at Kingston Mines	13,430	83,100	1,810	3,000	2,300
Fox River at Dayton	1,506	47,100	78	165	100
Kaskaskia River at Carlyle	1,960*	54,400*	7.7*	21	8.5
Big Muddy at Murphysboro	1,787	33,300	0	-	-
Iowa					
Mississippi River at Keokuk	61,100	327,000	5,000	11,200	7,700
Missouri					
Mississippi River at St. Louis	174,000	1,019,000	18,000	36,800	28,500
Indiana					
Wabash River at Vincennes	11,550	189,000	770	1,060	849
White River at Petersburg	11,630	183,000	533	685	474
Ohio River at Evansville	133,900	1,410,000	Not determined	805 16,200+	-
Kentucky					
Green River at Livermore	10,850	208,000	280	306	21
Pond River near Apex	257	21,800	0	-	-
Tradewater at Olney	328	7,960	0	-	-

* Prior to construction of Carlyle Reservoir

+ 30 consecutive day average disc. 10 yr. freq. (cfs) natural and modified

Cubic meters per second = cubic feet per second x 0.0283

northern portion of the region and from slightly hard to moderately hard in the southern portion (Geraghty, 1973; UMRBCC, 1970). In many rivers, dissolved solids can generally range from 200 to 700 ppm during some periods, that is, as low flow when groundwater contributes greatly to the streamflow. Sediment concentrations range from over 1900 ppm in western and southern Illinois to less than 270 ppm in Indiana and Kentucky. Acid mine drainage occurs in some rivers in Illinois and Kentucky. Selected chemical parameters of surface waters are presented in Table 20.

The major water use in the region is for industrial purposes and is equal to about nine times that of municipal use as presented in Table 21. Supplemental irrigation is a minor use in the region. The selected counties account for about 27 percent of the total 1970 water use in the region.

As with the Appalachian Region, the states in the Eastern Interior Region adhere to the riparian concept of surface water rights. Federal legislation, for example the Water Quality Act of 1965, also applies. Cooperation among the states in water resources planning and regulation occurs at the river basin level; however, this activity does not regulate water use within a state (ORBCC, 1968; UMRBCC, 1970).

Groundwater

The unconsolidated deposits (glacial-drift and alluvium) and the consolidated bedrock are the major aquifers in the region. Alluvial aquifers along major rivers (such as the Mississippi, Ohio, Illinois, and Wabash) have supplied wells with yields ranging from 0.28 to 3.79 cu m per minute (75-1000 gpm) and more. These wells have specific capacities from 0.057 to 0.34 cu m per minute (15-90 gpm) per foot of drawdown. An ancient buried bedrock valley of the preglacial Mississippi River underlies the present southern part of the Illinois River extending from Rockford through Peoria and westward to the Mississippi River. Yields from this alluvial aquifer range from 3.79 to 7.58 cu m per minute (1,000 to 2,000 gpm) (UMRBCC, 1970). Water levels in this aquifer are high; this results from a shift to surface water by large industrial users and an artificial aquifer recharge program.

A similar buried preglacial valley, the Mohomet Bedrock Valley, exists in east-central Illinois and probably also in west-central Indiana (Visocky and Schicht, 1969). However, this aquifer is heavily utilized at present. In many areas, sand and gravel aquifers in the glacial drift will also yield more than 1.9 cu m per minute (500 gpm) to an individual well (UMRBCC, 1970). Figure 72 identifies the expected yields from unconsoliated aquifers in the region.

The bedrock aquifers in the region consist of dolomites, limestones, and sandstones and are shown in Figure 73. In Indiana and Kentucky, ground-water information is scarce and limited to the shallow bedrock aquifers, but deep aquifers are also thought to exist in these areas. Yields of shallow limestone and dolomite aquifers vary widely; however, in many areas in Illinois these aquifers can yield more than 1.9 cu m per minute (500 gpm) (UMRBCC,

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TABLE 20. SELECTED CHARACTERISTICS FOR WATER QUALITY OF RIVERS IN THE EASTERN INTERIOR REGION* (Sources: ISWS,1973; USGS, 1970b, 1970c)

River	Average instantaneous discharge (cfs)	Dissolved silica (SiO_2)	Dissolved iron (Fe)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)
Illinois					
Rock River at Como	5,272	6.8	1.6^{+}	66.2	17
Illinois River at Peoria	18,382	5.5	2.1^{+}	119.7	37
Fox River at Dayton	1,499	40.2	11.5^{+}	79.3	26
Kaskaskia River at Shelbyville	676	6.8	3.1^{+}	93.3	35
Big Muddy River at Murphysboro	8,597	6.0	4.3^{+}	222.7	38
Mississippi River at East St. Louis	N.A.	8.5	4.2^{+}	56.5	17
Ohio River at Cairo	N.A.	4.2	2.8^{+}	64.8	24
Indiana					
Wabash River at Riverton	N.A.	7.5	0.1^{+}	96.2	25
Kentucky					
Green River at Munfordville	2,900	$11^{\#}$	N.A.	16	20
Tradewater River at Olney	411	$16^{\#}$	.04	236	4.0

* Time-weighted average in parts per million (ppm), for one selected year.
Cubic meters per second = cubic feet per second x 0.0283

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TABLE 20. (Continued)

River	Dissolved solids (residue at 180° C)	Alkalinity (bicarbonate) (as $CaCO_3$)	Total hardness (as $CaCO_3$)	pH	Sediment concentration
Illinois					
Rock River at Como	404‡	261	343	N.A.	N.A.
Illinois River at Peoria	431‡	178	305	N.A.	N.A.
Fox River at Dayton	404‡	250	329	N.A.	N.A.
Kaskaskia River at Shelbyville	457‡	235	347	N.A.	N.A.
Bid Muddy River at Murphysboro	458‡	54	240	N.A.	N.A.
Mississippi River at East St. Louis	296‡	157	196	N.A.	N.A.
Ohio River at Cairo	213‡	67	121	N.A.	N.A.
Indiana					
Wabash River at Riverton	398‡	187	290	8.2§	N.A.
Kentucky		Hardness ca,Mg	Noncarbonate hardness		
Green River at Munfordville	165	113	18	7.8	152 3,180†
Tradewater River at Olney	371	213	206	6.4	39 764†

+ Total iron
‡ Evaporation of filtered sample
§ At Hutsonville, Ill. (WY 1972)
# Average of less than 5 values
† Maximum daily
N.A. - Not available

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TABLE 21. ESTIMATED WATER USE FOR SELECTED COUNTIES IN THE EASTERN INTERIOR REGION (Sources: ORBCC, 1968; UMRBCC, 1970; ISWS, 1962)

River basin	1970 municipal use (mgd)	% of 1960 municipal population supplied by groundwater	1970 industrial use (mgd)	Total 1970 municipal & industrial water use in river basin (mgd)	% of 1970 total basin water use in the selected counties
Illinois					
Rock	8.7	100.0	37.9	333.8	13.9
Illinois	45.1	42.9	445.7	3788.1	12.9
Kaskaskia	43.8	22.3	732.9	306.2	21.6
Big Muddy	7.1	3.0	36.3	23.8	42.4
Saline	1.6	1.7	0	2.6	61.5
Indiana					
Wabash	20.7	24.1	22.5	626.8	7.1
Ohio (Evansville)	1.4	100.0	2.8	95.4	4.4
Kentucky					
Green	3.9	11.1	1.9	25.4	22.8
Tradewater	.4	100	.4	1.6	50.0*
Ohio (Evansville)	12.3	70.0	26.9	95.4	41.1

* Portion considered tributary to Ohio River main stem - Evansville.
Cubic meters per day = million gallons per day x 3785

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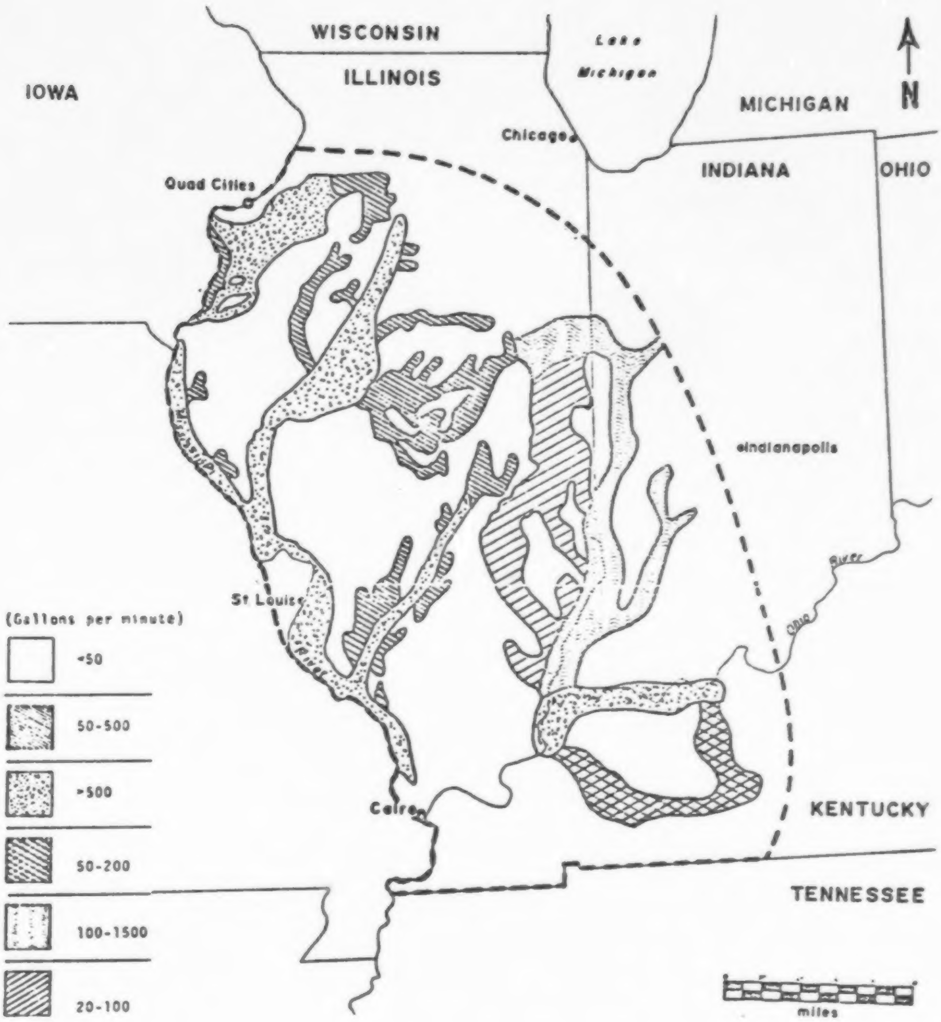
WISCONSIN
Lake Michigan
ILLINOIS
IOWA
MICHIGAN
N
Chicago
INDIANA
OHIO
Quad Cities
Indianapolis
St Louis
River
Ohio River
Cairo
KENTUCKY
TENNESSEE
(Gallons per minute)
<50
50-500
>500
50-200
100-1500
20-100
miles

Figure 72. Expected yields from unconsolidated aquifers in the Eastern Interior Region (Hittman, 1974).

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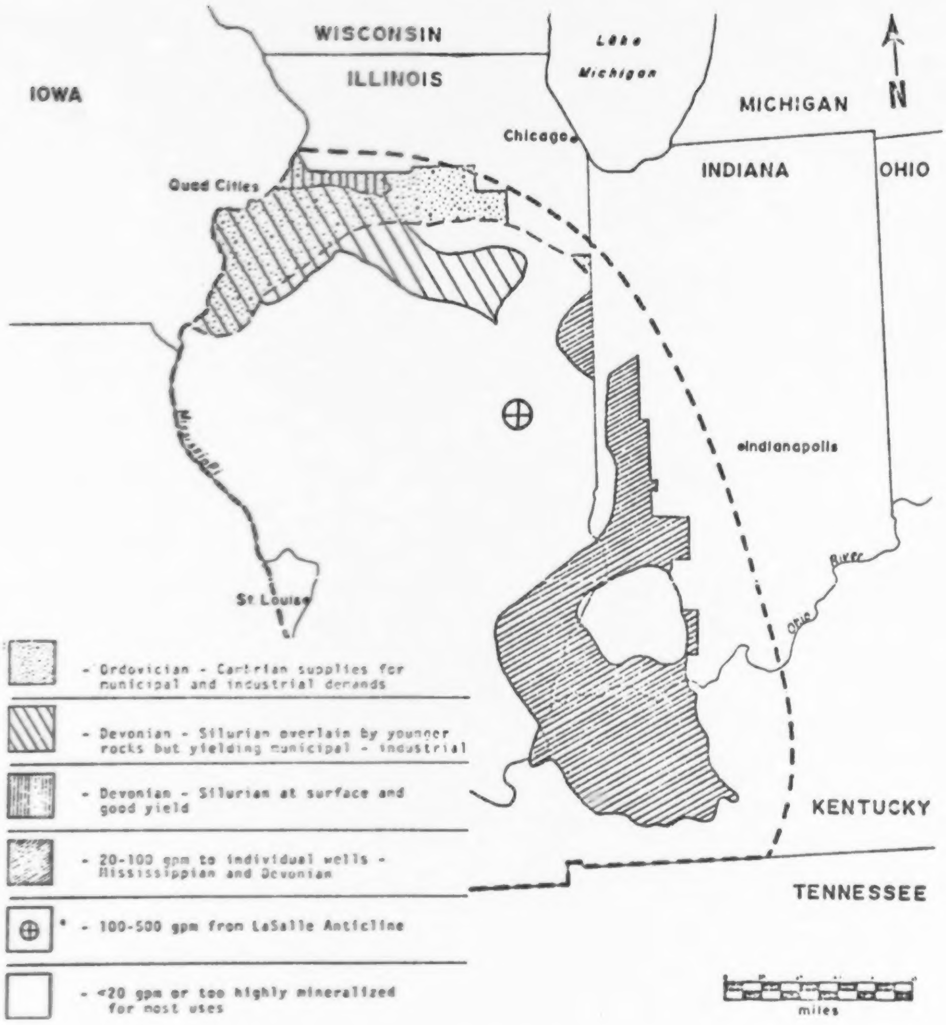
WISCONSIN
ILLINOIS
IOWA
Lake Michigan
MICHIGAN
N
Chicago
INDIANA
OHIO
Quad Cities
Mississippi
Indianapolis
Ohio River
St Louis
KENTUCKY
TENNESSEE
miles
- Ordovician - Cambrian supplies for municipal and industrial demands
- Devonian - Silurian overlain by younger rocks but yielding municipal - industrial
- Devonian - Silurian at surface and good yield
- 20-100 gpm to individual wells - Mississippian and Devonian
* - 100-500 gpm from LaSalle Anticline
- <20 gpm or too highly mineralized for most uses

Figure 73. Expected yields from bedrock aquifers in the Eastern Interior Region (Hittman, 1974).

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1970). Water in the deep aquifers is artesian, with yields from 0.379 to 1.14 cu m per minute (100 to 300 gpm). Heavy pumping has caused the dewatering of some aquifers in northeastern Illinois.

Water quality varies, depending upon the particular aquifer. In the alluvial and glacial drift aquifer, water is of good quality but hardness is usually high (more than 250 ppm) and iron content is greater than 0.3 ppm. In many areas, dissolved solids content is between 400 and 500 ppm. In the deeper aquifers, groundwater is very hard, ranging from 300 to 500 ppm; sulfate concentrations can exceed 250 ppm in some locations. Water in the upper portion of the deepest aquifer, the Mount Simon, is reportedly of good quality but it becomes saline (greater than 1,000 ppm) with depth (UMRBCC, 1970). Details on quality are discussed in the reports cited as references and are summarized in Table 22.

Municipalities and industries in this region rely heavily on groundwater. In some river basins, 100 percent of the municipal supply is obtained from groundwater. Rural homes also depend largely upon groundwater.

WESTERN INTERIOR REGION

Water resources of the Western Interior Region depend principally upon the flows of the major rivers running through the region. A network of reservoirs substantially regulates the flows of the major rivers. The quality of the surface water supplies is generally considered good. Groundwater availability is subject to local variation; it is most plentiful in the alluvial deposits. Several problems with the quality of the groundwater in the area place constraints on the use of groundwater resources.

Surface Water

Surface runoff from northeastern Missouri (the Salt River) enters the Mississippi River. Most runoff from Missouri and eastern Kansas enters the Missouri River. Runoff from southern Kansas, eastern Oklahoma, and western Missouri enters the Arkansas River.

Streamflow characteristics for rivers in the Western Interior Region are shown in Table 23. Annual lowflows commonly occur during late summer and fall; the smaller tributaries often approach zero flow during this time. The flows of the lower Missouri River and the Arkansas River are partially controlled by numerous reservoirs on their upstream reaches.

Flood flows are most severe during the spring. The streamflow in eastern Oklahoma has been well regulated by flood control and water conservation projects.

Data about surface water quality for selected streams in the Western Interior Region are shown in Table 24. Waters of streams in the Mississippi and Missouri Basin usually have lower concentrations of dissolved solids and chloride than streams in the Arkansas Basin.

TABLE 22. CHARACTERISTICS OF GROUNDWATER QUALITY IN THE EASTERN INTERIOR REGION
(Sources: ORBCC, 1968; UMRBCC, 1970)

Source	Well depths (m) (ft)	Depths to water (m) (ft)	Hardness (mg/1)	Sulfate (mg/1)	Chloride (mg/1)	Iron (mg/1)	Total dissolved solids (mg/1)
Unconsolidated Sediments							
Glacial and alluvial sand and gravel in the Ohio River valley	12-37 (40-120)	2-15 (5-50)	150-600	5-5	5-50	.2-3.5	200-900
Glacial and alluvial sands along former course of Ohio River, between Golconda and Ullin, IL	12-55 (40-180)	---	90-370	75-200	5-20	.2-3.0	170-500
Alluvial deposits in the valley of the lower Green River	31 (100)	9 (30)	130	10	12	0.3	---
Outwash and valley train deposits along lower Wabash (Terre Haute to mouth)	9-37 (30-120)	2-9 (5-30)	250-400	25-75	1-17	---	200-450
Outwash and valley train deposits in drainage of lower White (Martinsville to mouth)	14-37 (45-120)	3-9 (10-30)	250-400	25-90	1-35	---	350-370
Filled Teays (Mahomet) Valley from Tippecanoe County west	34-104 (110-340)	6-31 (20-100)	250-400	2-100	0-20	---	320-420
Bedrock Formations							
Sand and gravel of the Tertiary and Cretaceous Systems	122-31 (400-100)	---	150-300	5-25	5-75	1.5.0	200-350
Sandstones of the Pennsylvanian System	15-274 (50-900)	---	50-450	25-240	5-75	---	200-2100
Mississippian sandstone in Montgomery, Fountain and Putnam Co., IN	15-61 (50-200)	6 (20)	290-420	10-100	4-35	---	330-470
Devonian limestone and dolomite in Douglas and Champaign Co., IL	61-213 (600-700)	27-40 (90-130)	230-250	10	20-80	---	410-510

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TABLE 23. STREAMFLOW DATA FOR SELECTED STREAMS IN THE WESTERN INTERIOR REGION (Sources: OWRB, 1970, 1971; USGS, 1967; Johnson, 1972; KWRB, 1967; Skelton, 1970)

Stream	Station (of record)	Drainage area (mi^2)	Average discharge (cfs)	7 day - 10 yr. low flow (cfs)	Remarks
Mississippi River Basin					
Salt River	New London 1923-57	2,480		0.8	Partial upstream control at Clarence Cannon Reservoir
Mississippi River	Keokuk 1868-1965	119,000			99% of the time in any year flow is greater than 400 cfs
Missouri River Basin					
Grand River	Sumner 1925-58	6,880	3,700	25.	Most of basin is outside study area
Chariton River	Prairie Hill 1930-58	1,870	1,081	6.5	Partial regulation by Thomas Hill Reservoir
Marais Des Cygnes	Trading Post 12 years	3,230	1,920		50% of time yearly discharge is >827 cfs 10% of time yearly discharge is >128 cfs
South Grand	Browington 1922-58	1,660	1,027	no flow	7 day - 2 year low flow is 1.1 cfs - flow regulation at Kaysinger Bluff (now Harry S. Truman Reservoir)
Sac River	Stockton 1922-58	1,160	969	6.6	Most of basin is outside study area - flow regulation at Stockton Lake
Osage River	Osceola 51 years	8,200	5,100		Minimum daily discharge, period of record, is 3.6 cfs
Missouri River	Boonville 45 years	505,700	55,960		Minimum daily discharge-1800 cfs Regulation in study area by Melvern Reservoir

Square kilometers = square miles x 2.590
Cubic meters per second = cubic feet per second x 0.0283

(continued)

TABLE 23. (Continued)

Stream	Station (of record)	Drainage area (mi^2)	Average discharge (cfs)	7 day - 10 yr. low flow (cfs)	Remarks
Arkansas River Basin				10% low flow*	
Verdigris River	Inola 1945-62	7,911	4,483	45.	Flow partly regulated since 1963 by Cologeh Reservoir-average discharge during 1964-68 was 2,325 cfs and 10% lowflow = 50 cfs
Neosho River	Fort Gibson 1951-68	12,495	6,362	220.	Flow required by Fort Gibson Reservoir, Lake O'Cherokees, Lake Hudson and John Redmund Reservoir
Illinois River	Tahlequah 1936-68	959	837	100	Regulation with region by Tenkiller Ferry Reservoir
Canadien River	Whitfield 1939-65	47,576+	5,617	200	Flow regulated since 1964 by Eufala Reservoir. Average discharge during 1964-68 was decreased 10% lowflow = 10 cfs
Poteau River	Wister 1939-65	993	1,117	6	Flow regulated since 1949 by Wister Reservoir - 10% lowflow for 1949-65 = 2 cfs
Arkansas River	Van Buren, AR 1928-65	150,483‡	30,720	2100	Partial regulation by upstream reservoirs

* Indicates value of discharge in cfs which was exceeded 90% of time during period of record

+ 9,700 mi^2 probably non-contributing

‡ 22,241 mi^2 probably non-contributing

Square kilometers = square miles x 2.590
Cubic meters per second = cubic feet per second x 0.0283

TABLE 24. CHARACTERISTICS OF WATER QUALITY FOR SELECTED STREAMS IN THE WESTERN INTERIOR REGION (Sources: USGS, 1967; OWRB, 1970, 1971; KWRB, 1967, 1972)

Stream Location	Sulfate (ppm) max	Sulfate (ppm) min	Chloride (ppm) max	Chloride (ppm) min	Dissolved solids (ppm) max	Dissolved solids (ppm) min	Hardness as $CaCO_3$ (ppm) max	Hardness as $CaCO_3$ (ppm) min	
Arkansas River Muskogee, OK	265	63	1110	248	2140	695	490	176	
Arkansas River Sallisaw, OK	172	15	575	29	1380	169	385	104	
Verdigris River Oologah, OK	55	37	252	58	694	348	298	214	
Neosho River Below Fort Gibson Res.	65	21	23	5.1	272	138	190	82	
Illinois River Gore, OK	33	3.2	300	1.2	740	40	226	33	
Canadien River Whitefield, OK	234	1.6	940	3.5	1860	68	540	36	
Poteau River Braden, OK	31	11	25	3.0	150	54	72	17	
Canadien River Whitefield, OK	44		152		457		711		Average of annual weighted average, 1958-64, 1967
Arkansas River Sallisaw, OK	55		133		436		168		Average of annual weighted average, 1959-61
Marmaton River Fort Scott, KS					399	159	324	96	Water yr 1967-68; pH from 7.1-8.2
Osage River Ottawa, KS	84	23	22	<1	395	141	302	96	Water yr 1967-68; pH from 7.4-7.9
Chariton River Prairie Hill, MO	138	33	7.4	4.1	424	141	317	103	Water yr 1967-68; pH from 7.3-8.1
Salt River New London, MO	95	10	14	3.5	342	66	252	40	Water yr 1967-68; pH varied from 7.0-8.0

Along reaches of the Chariton River (Missouri Basin), acid mine drainage depresses the pH of the waters to 3.0 or less. During a recent water year on the Chariton River (East Fork), sulfate concentration ranged from about 175 to 851 mg per liter, and iron and magnesium concentrations greatly exceeded current drinking water standards.

On balance, however, the overall water quality of the region is considered good. Severe water quality problems arise, however, when municipal wastewater enters certain streams during seasonal lowflow intervals.

Water use data for Kansas, Oklahoma, and selected parts of Missouri are given in Table 25. Large-scale industrial demands are usually located close to the Arkansas and Missouri Rivers. The Spring River, in southeastern Kansas, is suitable for meeting many industrial demands (USGS, 1967; OWRB, 1970, 1971; KWRB, 1967; MBIC, 1971).

Irrigation demands in the region are small with less than 1619 hectares (4000 acres) irrigated in Missouri in 1965 and Oklahoma in 1973. In 1965 less than 432,000 cu m (350 acre-ft) of water was used for irrigation in four eastern Kansas counties. Most of the irrigated croplands are adjacent to major streams, where the alluvium yields are considered high.

In northeastern Oklahoma, all reservoirs on the Neosho River are used for power generation. Other important power pools are at Kaysinger Bluff, Stockton Lake and Efala.

Dependable, year-round supplies of good quality water in large volumes can be obtained from the three major rivers of the region: the Arkansas, Missouri, and Mississippi. The Spring River, in southeastern Cherokee County, Kansas, also provides a smaller volume of dependable supplies. Development of the water resources on tributary streams, however, would require the construction of reservoirs or off-channel impoundments.

Existing reservoirs are capable of storing over 2.9×10^9 cu m (2.4×10^6 acre-ft) of water for conservation and low-flow augmentation. Some of this water may be available to meet future water demands. An even larger amount of flood control storage is presently in existence; it may be possible to utilize this supply in meeting new demands.

As a result of agreements between certain states, reservoir construction was allocated on several streams. The 1970 Arkansas River Basin Compact between Arkansas and Oklahoma divided the streamflow of the Illinois and Poteau Rivers; Arkansas receives no more than 60 percent of the flow, while Oklahoma was limited to 60 percent of the flow from the Arkansas Basin. A 1965 agreement between Kansas and Oklahoma also allocated reservoir construction on the Neosho and Verdigris Rivers. Upstream agreements between Colorado and Kansas may act to limit the streamflow of the Arkansas River.

Unless supplies are obtained from one of the three largest rivers of the region, large-scale water supplies must come from reservoir and storage projects. On tributary streams, dependable, year-round streamflows are not sufficiently large to support direct withdrawals for meeting future needs. Interstate agreements may affect the development of future water supplies through limitations on stream withdrawal and reservoir construction. This is especially true for the Arkansas River Basin.

Groundwater

The Missouri River marks the approximate southern extent of the last continental glaciation. Consequently, glacial drift deposits overlie the bedrock formations only in the northern part of the Western Interior Region. Throughout most of the region, groundwater supplies are developed from either river valley alluvial deposits or consolidated bedrock formations.

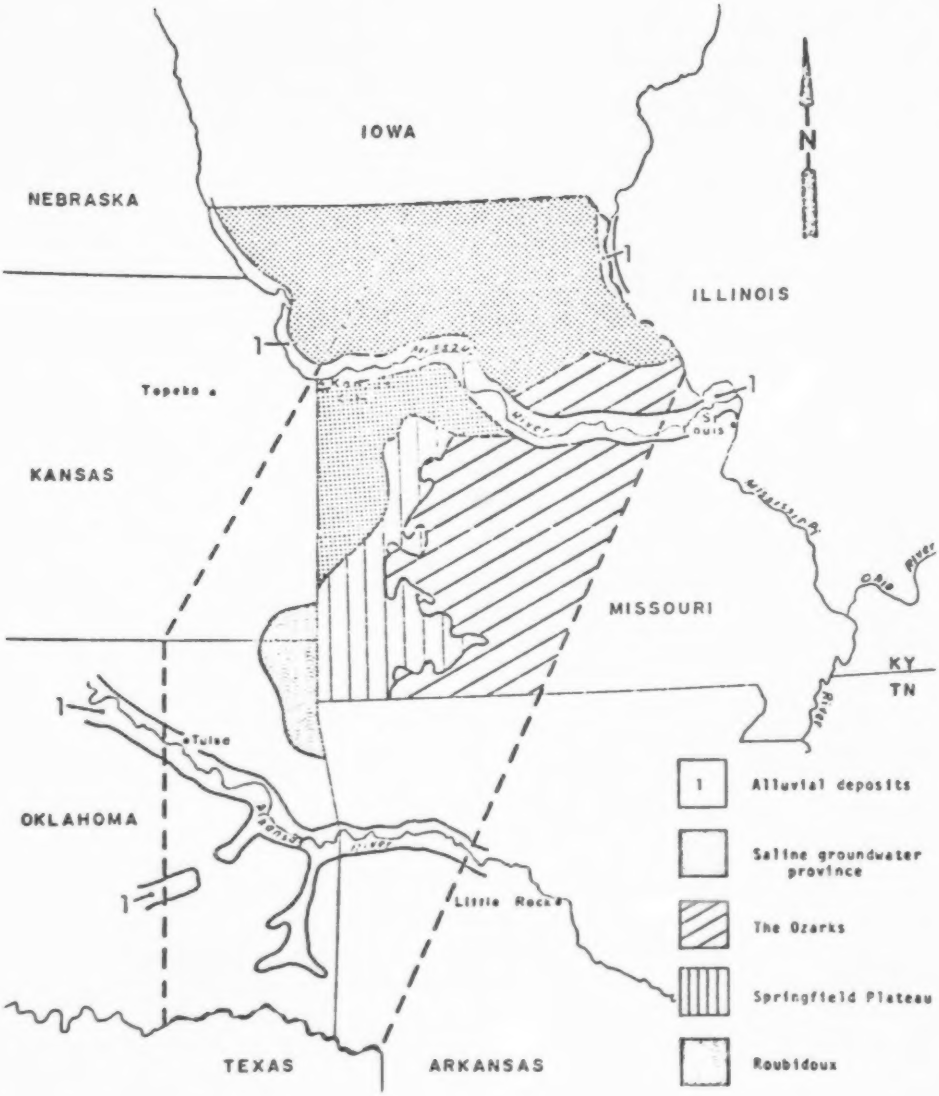
The groundwater characteristics of the region are shown in Figure 74. Significant alluvial deposits are generally confined to the Arkansas and Missouri River Valleys, with essentially no deposits in the stream valleys of tributaries lying between these two rivers. The exception is in the lower reaches of the Verdigris River, south of the Arkansas River.

The most favorable areas for groundwater development from the glacial drift are the buried sand and gravel filled channels of pre-glacial streams. Over much of the area, the glacial drift is thin or absent and, consequently, groundwater yields are limited. Because of the variable thickness and composition of the glacial drift, there is a wide variation in well yields from site to site. In a study of the possible development of groundwater supplies from the glacial drift of Linn, Sullivan, and Chariton Counties, it was estimated that 6 percent of the area might yield from 0.76 to 3.79 cu m per minute (200 to 1000 gpm), but that over 44 percent of the drift area could not sustain domestic wells at 0.057 cu m per second (15 gpm).

In the Western Interior Region, the development of groundwater supplies from bedrock formations is limited for two reasons: the water-bearing characteristics of the formations and the generally poor quality of the water. Most of the geologic units underlying the study area are composed of shale, thin limestones, thin sandstone, and siltstone. Generally the formations dip to the south and west; they become more mineralized with depth.

Table 26 indicates groundwater quality data for the Western Interior Region. The best water quality occurs in the alluvial deposits. The quality of the alluvial waters is often related to the quality of the surface waters that recharge the deposit. However, where withdrawals do not induce recharge from the stream, water quality is less dependent on the nature of the surface water.

Throughout the region, several groundwater quality problems contrive to essentially prohibit groundwater use. These problems include: high iron contents, high dissolved solids, and salinity. Salinity is greatest in the Saline Groundwater Province in the Missouri Basin, where groundwater


IOWA
NEBRASKA
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N
1
Missouri
Topeka
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KY
TN
River
Tulsa
OKLAHOMA
Arkansas
River
Little Rock
TEXAS
ARKANSAS
1 Alluvial deposits
Saline groundwater province
The Ozarks
Springfield Plateau
Roubidoux

Figure 74. Groundwater provinces of the Western Interior Region (USGS, 1967).

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TABLE 25. WATER USE IN THE WESTERN INTERIOR REGION (Sources: USGS, 1967; OWRB, 1974; KWRB, 1972; MDEQ, 1974)

a. Kansas water use (in ac-ft/yr)

	Linn County	Bourbon County	Crawford County	Cherokee County
1965 Manufacturing	1	97	241	5,724
1965 Urban domestic	275	1,438	3,359	1,644
1965 Livestock	975	1,257	867	603
1965 Total	1,764	3,281	5,643	174,414*
2020 Manufacturing	777	2,921	9,981	10,910
2020 Urban domestic	1,012	1,895	7,152	3,826
2020 Livestock	2,937	2,759	2,504	2,248
2020 Total	6,423	18,556*	22,712	23,356

b. 1973 Water use in Oklahoma (in ac-ft/yr)

	Municipal		Industrial		Total		
County	Ground-water	Surface	Ground-water	Surface	Ground-water	Surface	Grand total
Craig	30	1,348	0	160	30	1,509	1,539
Haskell	1	818	0	147	1	965	974
LeFlore	0	1,839	0	365	431	2,218	3,752
McIntosh	0	0	0	564	0	567	567
Muskogee	10	3,417	21	102,400	898	106,939	107,837
Nowata	0	1,290	0	0	0	1,290	1,290
Pittsburgh	0	5,112	0	1,586	104	7,004	7,334
Rogers	0	3,330	0	7,391	0	11,255	11,374
Sequoyah	0	2,166	0	3,277	996	5,905	6,701
Wagoner	0	2,987	0	0	0	3,053	3,053
Washington	0	1,926	0	0	0	2,357	2,357

c. Estimated 1973 water use by municipalities and county water supply districts in Missouri(ac-ft/yr)

	From groundwater	From surface water	Total
Designated counties north of Missouri River	17,837	15,934	33,771
Designated counties south of Missouri River	5,721	3,614	9,335
Sum =	23,558	19,548	43,106

* Most of other demand projected to utilities.
Cubic meters = acre - feet x 1233.4

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TABLE 26. GROUNDWATER QUALITY IN THE WESTERN INTERIOR REGION (Sources: USGS, 1967; Bedinger and others, 1963)

a. Water from Paleozoic aquifers in Missouri

County	Depth (m)	Iron (ppm)	Sulfate (ppm)	Chloride (ppm)	Dissolved solids (ppm)	pH	Hardness as $CaCO_3$ (ppm)
Bates	348	2.3	165	2,520	5,060	-	
Chariton	280	-	1,270	5,060	11,600	-	
Johnson	320	2.2	62	834	1,910	-	311
Lafayette	291	8.1	92	1,980	3,960	-	742
Pike	389	0.05	1,000	4,550	9,580	-	1,710
Randolph	361	-	876	723	3,000	-	771
Schuyler	459	-	1,260	542	2,870	-	429
Vernon	335	0.1	62	610	1,530	7.4	364

b. Water from glacial drift in northern Missouri

County	Depth (m)	Iron (ppm)	Sulfate (ppm)	Chloride (ppm)	Dissolved solids (ppm)	pH	Hardness as $CaCO_3$ (ppm)
Chariton	42	0.54	33	103	576	7.6	238
Linn	26	0.38	16	21	515	7.5	280
Putnam	46	0.82	291	17	933	7.5	515

c. Water from alluvium of Missouri River

County	Depth (m)	Iron (ppm)	Sulfate (ppm)	Chloride (ppm)	Dissolved solids (ppm)	pH	Hardness as $CaCO_3$ (ppm)	
Clay		15	143	19	535	7.0	290	Outside region (upstream)
Callaway		20	14	7.1	452	7.2	402	

d. Water from Arkansas valley alluvium in Arkansas

County	Sulfate max (ppm)	Sulfate min (ppm)	Iron max (ppm)	Iron min (ppm)	Chloride max (ppm)	Chloride min (ppm)	Ca, Mg max (ppm)	Ca, Mg min (ppm)
Johnson	71	1.	21	0.09	32	4.0	840	140
Logan	45	0.	19	0.00	53	2.0	546	95
Franklin	58	2.	25	0.02	225	2.2	370	21
Sebastian	-	-	56	0.01	75	5.5	634	178

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TABLE 26. (Continued)

e. Area in Oklahoma section of Western Interior

Formation	Hardness Max	Hardness Med	Hardness Min	Sulfate Max	Sulfate Med	Sulfate Min	Chloride Max	Chloride Med	Chloride Min	Total dissolved solids Max	Total dissolved solids Med	Total dissolved solids Min
	(ppm)			(ppm)			(ppm)			(ppm)		
Roubidoux (including Gasconade & Potosi-Eminence) (32 analyses)	420	146	118	124	16	0.3	780	79	1.6	1,570	276	140
Alluvium and terrace deposits in Oklahoma (17-18 analyses)	540	180	34	519	26	0.0	265	22	0.0	1,140	335	105
Pennsylvanian & Upper Mississippian Rocks North of Arkansas River in Oklahoma (58 samples)	1,300	268	28	2,090	75	1.8	1,520	37	1.8	3,220	576	117
Shale, siltstone and sandstone south of Arkansas River in Oklahoma (82-84 samples)	3,020	144	4	3,150	36	4.2	715	44	2	5,160	581	63

salinities reportedly range from 1000 to 20,000 ppm. The principal sources of water quality data for this region include USGS (1967), OWRB (1970, 1971), Johnson and others (1972), Beddinger and others (1963). Information on the uses of groundwater in certain parts of the Western Interior Region is given in Table 25. Over most of the region, groundwater supplies are usually limited to less than 0.2 cu m per minute (50 gpm) (in or for) each individual well. The exceptions to this are the alluvial deposits of the major rivers, and the Roubidoux sandstone, in southwestern Kansas and northeastern Oklahoma.

The alluvium of the Canadian and Poteau River is extensive and yields have been estimated at up to 0.76 cu m per minute (200 gpm)(in or for) individual wells. Individual wells tapping the Verdigris River alluvium usually yield from 0.04 to 0.28 cu m per minute (10 to 75 gpm). Groundwater yields along the Arkansas River are usually within the range of 0.76 to 3.79 cu m per minute (200 to 1000 gpm), while 9 cu m per minute (500 gpm) or more is common from wells drilled in the Missouri River alluvium.

In the Mississippi and Missouri Basins within the study area, the bedrock aquifers usually yield up to 0.90 cu m per minute (250 gpm) from individual wells. In an east to west direction across the region, bedrock yields usually decrease and salinity increases. In large areas of the Kansas portion of the region, adequate stockwater or domestic yields cannot be obtained from the shales and thin limestones of the Cherokee, Marmation, and Pleasanton Formations. The quality of groundwater below 61 m (200 ft) in Kansas is usually too saline for use. In Missouri, the depth of fresh-water is greater, but it is seldom found below 274 m (900 ft) (KWRB, 1972; USGS, 1967).

Within the Arkansas River Basin, most of the area is underlain by shale, siltstone, and limestone, all of which yield only a fraction of a gallon to a few gallons per minute (in or for) individual wells (OWRB, 1970; 1971). The Atoka Formation (shale, siltstone, sandstone) is the major aquifer within Arkansas (Wood, 1959). The Atoka is exposed in parts of Sequoyah and adjacent Oklahoma counties, but dips under younger formations to the south and west. The average yield of the Arkansas River Basin bedrock formations is probably less than 0.04 cu m per minute (10 gpm). Individual wells rarely exceed discharges of 0.2 cu m per minute (50 gpm).

The Roubidoux Sandstone is an exception to the general rule that the Western Interior bedrock formation yields very limited quantities of water. Over 7.8 cu m per minute (2000 gpm) have been obtained from the Roubidoux in Cherokee County in Kansas. Water quality deteriorates to the west, however, and only in the northeastern part of Craig County (Oklahoma) can usable water be obtained from the Roubidoux.

Because groundwater supplies are extremely limited in the Western Interior, large-scale groundwater developments may occur. However, such development is only possible after desalination techniques become economical.

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SECTION 7

MAJOR SOIL TYPES OF THE EASTERN COAL PROVINCES

OVERVIEW

In this section, generalized soils information is supplied on a region-by-region basis. The information covers those soil characteristics usually considered important by planners who assess the impacts of mining. These include the general physical and chemical properties of the surface and subsoils, soil erodibility, and the overall rating of the soils with respect to the soil capability classes. The Soil Conservation Service of the U.S. Department of Agriculture publishes soil survey reports for specific counties in the various states; these reports furnish more detailed information about the soils and soil capability classes in each of these regions.

The analysis and importance of soils with respect to surface and groundwater flow considerations are reviewed in Volume 4, Mine Hydrology. The importance and use of soils in mine drainage control and in the treatment of acid mine drainage are covered in Volume 5, Mine Drainage Control and Monitoring. The influence of soils in evaluating the suitability of the mine site to support various alternatives for post mining land use are discussed in Volume 6, Mine Land Planning.

The materials contained in this section were adapted from a combination of published and unpublished background data which was prepared by Hittman Associates for the Energy Research and Development Administration (Hittman, 1974). That data were condensed from five principal sources which include USGS (1970a), Austin (1972), SCS (1971), Box and others (1947), and Shantz (1938).

APPALACHIAN REGION

The dominant soils of the Appalachian Region are summarized in Figure 75. The Appalachian Region is discussed on the basis of geological areas; in the following pages, the soils of the Eastern Ohio Till Plain, the Western Allegheny Plateau, the Central Allegheny Plateau, the Eastern Allegheny Plateau and Mountains, the Cumberland Plateau and Mountains, and the Sand Mountain area are discussed.

Eastern Ohio Till Plain

The dominant soils of this northwestern portion of the Appalachian Region include the Gray-Brown Podzolic Series: Wooster, Canfield, Mahoning,

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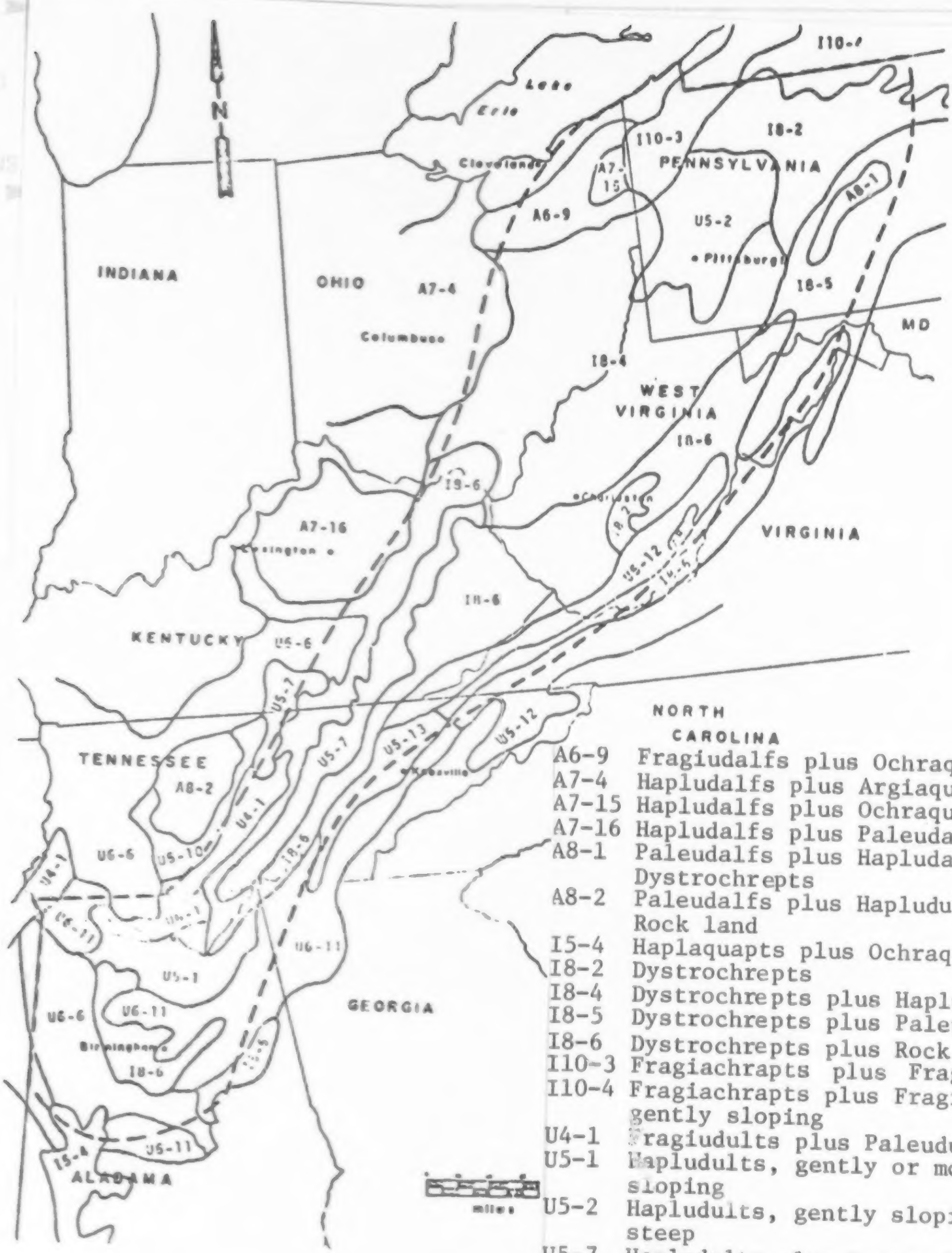
N
Lake
Erie
Cleveland
I10-4
I10-3
I8-2
A7-15
PENNSYLVANIA
A8-1
A6-9
U5-2
Pittsburgh
I8-5
MD
INDIANA
OHIO
A7-4
Columbus
I8-4
WEST VIRGINIA
I8-6
I5-6
Charleston
A7-16
Lexington
VIRGINIA
U5-12
I4-5
I8-6
KENTUCKY
U5-6
U5-7
NORTH CAROLINA
TENNESSEE
A8-2
U5-7
U5-13
U5-12
Knoxville
U4-1
I8-6
U6-6
U5-10
U4-1
U6-11
U4-1
U6-11
U5-1
U6-6
U6-11
GEORGIA
Birmingham
I8-6
U6-11
I5-4
ALABAMA
miles

A6-9	Fragiudalfs plus Ochraqualfs
A7-4	Hapludalfs plus Argiaquoils
A7-15	Hapludalfs plus Ochraqualfs
A7-16	Hapludalfs plus Paleudalfs
A8-1	Paleudalfs plus Hapludalfs and Dystrochrepts
A8-2	Paleudalfs plus Hapludults and Rock land
I5-4	Haplaquapts plus Ochraqualfs
I8-2	Dystrochrepts
I8-4	Dystrochrepts plus Hapludalfs
I8-5	Dystrochrepts plus Paleudalfs
I8-6	Dystrochrepts plus Rock land
I10-3	Fragiachrapts plus Fragiaquapts
I10-4	Fragiachrapts plus Fragiaquapts, gently sloping
U4-1	Fragiudults plus Paleudults
U5-1	Hapludults, gently or moderately sloping
U5-2	Hapludults, gently sloping to steep
U5-7	Hapludults plus Dystrochrepts
U5-10	Hapludults plus Hapludalfs
U5-12	Hapludults plus Paleudults
U5-13	Hapludults plus Paleudults and Dystrochrepts
U6-1	Paleudults
U6-6	Paleudults plus Hapludults
U6-11	Paleudults plus Rhodudults

Figure 75. Major orders and suborders of soils in the Appalachian Region (USGS, 1970).

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Ellsworth, and Rittman. These soils developed from medium-to-fine textured glacial till. Other Gray-Brown Podzolics include the Chili Series (developed from coarse-textured glacial outwash) and the imperfectly drained Ravenna and Wadsworth Series. Under the 1965 soil survey nomenclature, the Gray-Brown Podzolics conform most closely with the so-called Alfisols.

The Gray-Brown Podzolic soils developed under hardwood forests in the temperate, humid climate of northeastern Ohio. These soils have a surface texture which ranges from sandy loam to silty clay loam. The subsoils contain higher percentages of clay than the surface soils, and, in turn, the subsoils are underlain at depths of two to five feet by a light-colored parent material. The entire solum is acid. Reports indicate that the permeability of the undisturbed subsoil ranges from slow to moderate. These soils occur on gently to moderately sloping areas.

Gray-Brown Podzolic soils are used for pasture as well as for the production of row and small crops. The dominant soil limitations arise from overland erosion, shallowness, stoniness, and droughtiness. Although essentially all of the area is in farms, less than 20 percent of the area is in cropland status. From 50 to 60 percent of the area is considered unsuited for tillage, which places the area in the land capability classes V - VIII.

Other soils found in this area are the Low-Humic Gley soils ("Mollisols" in the 1965 nomenclature) represented by the Trumbull Series. These soils developed in flats and depressions in the Middle West under herbaceous plants or swamp forest. The thick surface soil layers are black and contain high percentages of organic matter (1 percent or greater). The water-logged soils occur naturally as meadow or forest land.

Humic-Gley soils must be drained for general crop production or when they are not drained, they can be used for pasture and woodland. The dominant soil limitations are from shallowness, stoniness, wetness, and droughtiness (USDA, 1941). About one-third of the soils are suitable for cultivation (classes I - IV); the remainder are unsuitable (classes V - VIII).

There are also some Inceptisols (Sols Bruns Acides) in this area. These soils generally occur on steep slopes and in association with rocklands.

Western Allegheny Plateau

This small area of soils is located in Ohio, southwest of the Eastern Ohio Till Plain. The dominant soil group is the Gray-Brown Podzolic (Alfisols), consisting of the Gilpin, Hanover, Keene, and Wellston Series. These soils occupy the rolling ridge tops. The Sols Bruns Acides, represented by the Muskingum Series, occur in the less extensive rolling to steeply sloping area.

The Sols Bruns Acides great soil group was formed under hardwood forest in the cool, temperate, humid climate of eastern Ohio. The entire solum is usually strongly acid, but in some areas the parent material may be calcareous at a depth of several feet. Reports indicate that the permeability of the undisturbed solum is slow to moderate.

Central Allegheny Plateau

This area comprises over 48,000 sq km (19,000 sq mi) in the states of Ohio, Pennsylvania and West Virginia. The major soils of this area are the Inceptisols (Dystorchrepts, formerly the Sols Bruns Acides, some Brown Podzolic and Gray-Brown Podzolic, and rockland). The Muskingum Soil Series is representative of Sols Burns Acides while the Gilpin Series is representative of the Gray-Brown Podzolic. Both of these groups of soils were derived from interbedded sandstones and shales, located largely on steep (10 to 25 percent or more) slopes. The parent material in some places is calcareous at a depth of several feet, but generally it is acid throughout. The Upshur, Belmont, Westmoreland, and Guernsey Soil Series are representative of the Gray-Brown Podzolic soils (Alfisols), which are underlain by calcareous shales and limestones.

There are alluvial soils of the Huntington and Lindside Series on the broad plains of the Ohio River and its larger tributaries. These soils are the best agricultural soils of the region.

Substantial areas of Ultisols (Haplundults, formerly the Red-Yellow Podzolic soils) are reported in southwestern Pennsylvania. These soils, which include the Cavode and Wharton Series, developed on the gently sloping to rolling ridge tops; the ridge tops are underlain by clay shales.

The Red-Yellow Podzolic soils developed mainly under mixed forests in a warm, humid climate. These soils characteristically possess a thick red, yellowish-red, or bright yellowish-brown subsoil; the subsoil has an accumulation of clay, and iron and aluminum oxides. The parent materials contain clays and siliceous materials. The entire solum of these soils is acid. Reports indicate that the permeability of the undisturbed subsoils is moderate to slow.

Eastern Allegheny Plateau and Mountains

This is an area of about 41,000 sq km (16,000 sq mi); it is in the states of Pennsylvania, Maryland, and West Virginia. The principal great soil groups found in the area include the Sols Burns Acides (Dekalb, Calvin, and Lehew), which are derived from acid gray sandstones and red shales. The sandstones and shales are located on the extensive steep slopes of the area. The Gray-Brown Podzolic soils (Gilpin and Belmont), which are located on steep slopes, occur in association with the Dekalb and other soils. The Gilpin soils were derived from acid shales, while the Belmont soils were derived from red, calcareous shales.

Less extensive areas of Red-Yellow Podzolic soils (Clymer, Cookport, Wharton, and Cavode) occupy the level to rolling ridge tops, which are underlain by acid sandstone and shale materials.

Cumberland Plateau and Mountains

This area is about 65,000 sq km (25,000 sq mi), and it includes Kentucky, Tennessee, and West Virginia. The major soil groups include the Sols Burns

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great soil groups, which are represented by the Muskingum and DeKalb Series, and the Lithosols group, which is represented by the Ramsey, Weikert, and Montevallo. All of these soils occur on steep, hilly slopes throughout the area.

In the northern part of the area, located on the undulating and rolling plateau slopes, are the Gray-Brown Podzolics (Willston and Gilpin). The Red-Yellow Podzolics of the Hartsells, Clymer, and Jefferson Series are located on the smooth plateau tops as well as on the foot slopes in the southern valleys.

The alluvial soils (Pope and Philo) occur on floodplains in the narrow valleys.

Sand Mountain Area

This 23,000 sq km (8700 sq mi) area lies entirely in Alabama. The major soil group found on the steep mountain sides and valley walls is the Lithosol, represented by the Ramsey Series.

On the smooth plateaus, there are Red-Yellow Podzolic soils (Hartshells and Albertville) and the Sols Bruns Acides group, represented by the Crossville Series.

The Lithosols have been described as being shallow and underlain by bedrock. The Lithosols of Alabama were developed under many kinds of natural vegetation and a warm, humid climate. These soils are presently covered with vegetation native to Alabama.

The Soil Conservation Service of the U.S. Department of Agriculture publishes soil survey reports for specific counties in the various states; these reports furnish more detailed information about the soils and soil capability classes in each of these regions.

EASTERN INTERIOR REGION

The distribution of the principal soils of the Eastern Interior Region is shown in Figure 76.

Northern, Eastern and Western Illinois

The Mollisols (Argiudolls, formerly the Brunizems and Reddish Prairie soils) comprise 49 percent of the soils of Illinois. These soils developed largely from glacial drift and loess, which was under the influence of prairie vegetation. The soils on the major river floodplains, however, developed under mixed forest grasses. The dark brown to black-colored topsoils average more than one percent organic matter. The A-horizon usually has a base saturation greater than 50 percent, with calcium as the predominant base.

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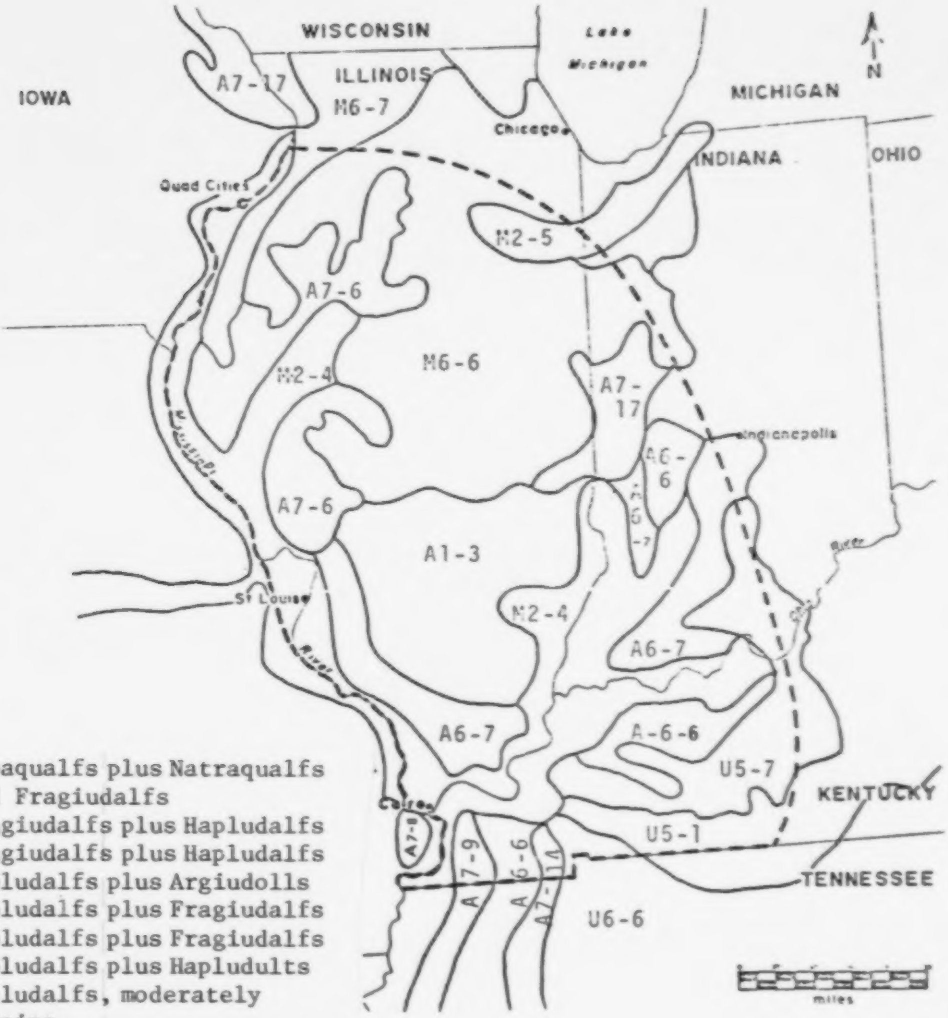
WISCONSIN
Lake Michigan
N
IOWA
A7-17
ILLINOIS
M6-7
MICHIGAN
Chicago
INDIANA
OHIO
Quad Cities
M2-5
A7-6
M2-4
M6-6
A7-17
Indianapolis
A6-6
A6-7
Mississippi
A7-6
A1-3
St Louis
M2-4
River
Ohio River
A6-7
A6-7
A-6-6
U5-7
KENTUCKY
Cairo
A7-8
A7-9
A6-6
A7-14
U5-1
TENNESSEE
U6-6
miles

A1-3	Albaqualfs plus Natraqualfs and Fragiudalfs
A6-6	Fragiudalfs plus Hapludalfs
A6-7	Fragiudalfs plus Hapludalfs
A7-6	Hapludalfs plus Argiudolls
A7-8	Hapludalfs plus Fragiudalfs
A7-9	Hapludalfs plus Fragiudalfs
A7-14	Hapludalfs plus Hapludults
A7-17	Hapludalfs, moderately sloping
M2-4	Haplaquolls plus Udifluvents, Hapludolls and Hapludalfs
M2-5	Haplaquolls plus Udipsamments
M6-6	Argiudolls plus Haplaquolls
M6-7	Argiudolls plus Hapludalfs and Haplaquolls
U5-1	Hapludults, gently or moderately sloping
U5-7	Hapludults, plus Dystrochrepts
U6-6	Paleudults plus Hapludults

Figure 76. Major orders and suborders of soil in the Eastern Interior Region (USGS, 1970).

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About 75 percent of the area is in cropland status; 10 percent of the area is pasture, and 5 percent (steep valley sides and bottomlands) is forested. The dominant soils' limitations are erosion by water and wind and poor internal drainage. The prairie soils developed on slopes ranging from less than 4 to more than 15 percent. The soils of Illinois are grouped into the highest land capability classes (I through IV).

Southern Illinois and Southwestern Indiana

The Alfisols (formerly the Planosols) are the dominant soils in this area. They differ from the Mollisols in having thinner topsoil depth (less than 10 in.), less than one percent organic matter, lighter colored surface layers, and a base saturation of about 40 percent. Alfisols were derived from wind blown materials (loess) overlying the old glacial till on level to gently sloping areas. The surface soil overlies a claypan; the claypan is underlain by less clayey material.

From 50 to 60 percent of these soils are in cropland status. Essentially all of the southern Illinois area is in farms. About 10 percent of the soils are in permanent pastures of tame and native grasses.

In the extreme southwestern part of Indiana, the land capability classes are similar to those in Illinois (I-IV). In southern Illinois and the extreme southwestern part of Indiana, the dominant soil limitations arise from water and wind erosion; in southern Indiana, soil limitations arise from shallowness and stoniness.

Western Kentucky and Southern Indiana

The Alfisols (Fragiudalfs, formerly the Gray-Brown Podzolics) are the dominant soils on the smooth flats and low hills. In western Kentucky, the alluvial soils on the broad floodplains are also important for crop production.

About 35 percent of the soils in southern Indiana, and about 51 percent of those in western Kentucky, are in a cropland status. Most of these soils are grouped into intermediate land capability classes (IV through VI). Major soil limitations arise from erosion by rainfall and surface runoff.

WESTERN INTERIOR REGION

The dominant soils of the Western Interior Region are shown in Figure 77.

Northern Missouri

Two major orders of soils, the Alfisols and the Mollisols, can be found in northern Missouri. The Alfisol group consists of the Albaqualfs (formerly Planosols) and the Hapludalfs (formerly Gray-Brown Podzolic soils). Albaqualf soils occupy slopes of less than 10 percent. Characteristically, these soils

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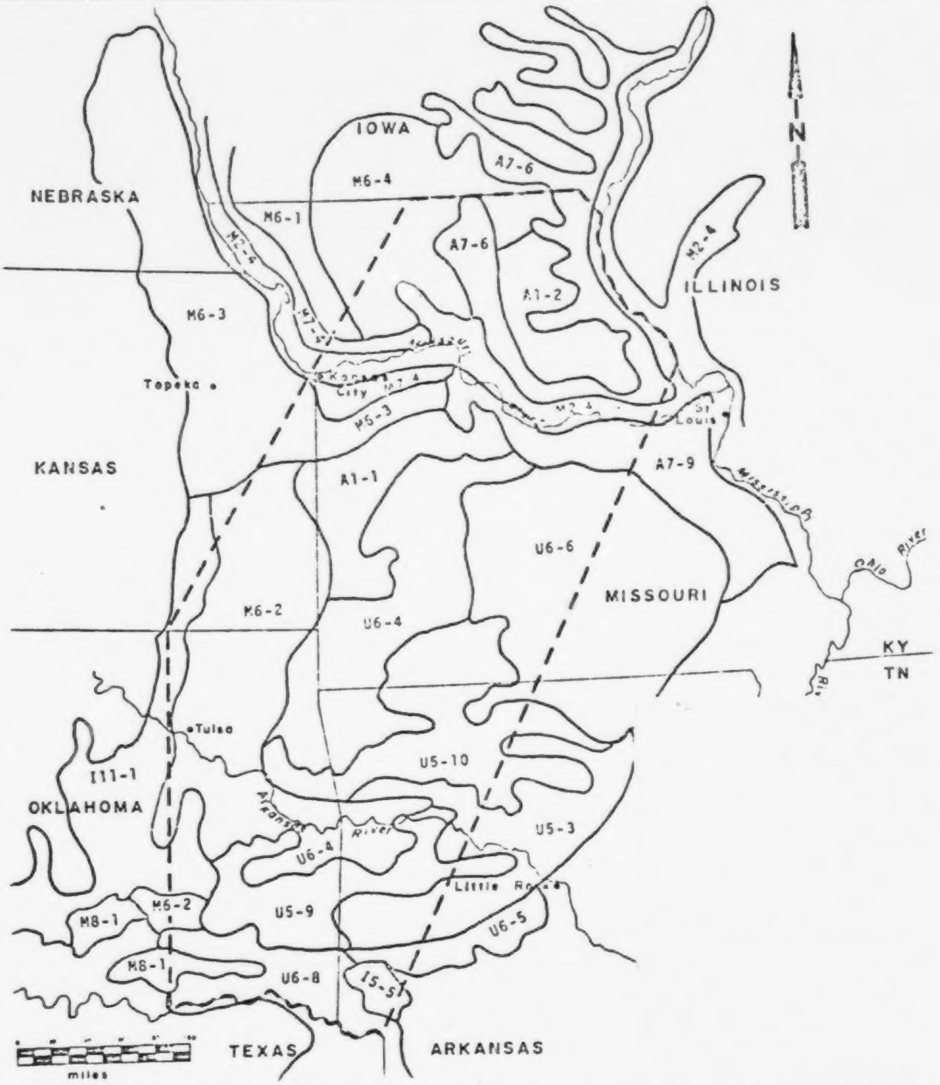
IOWA
NEBRASKA
ILLINOIS
KANSAS
MISSOURI
OKLAHOMA
TEXAS
ARKANSAS
KY
TN
N
M6-4
A7-6
M6-1
M2-4
A7-6
A1-2
M2-4
M6-3
M7-4
Kansas City
M7-4
Topeka
M6-3
M2-4
St Louis
A1-1
A7-9
Mississippi R
Ohio River
U6-6
M6-2
U6-4
Tulsa
I11-1
U5-10
Arkansas River
U5-3
U6-4
Little Rock
M8-1
M6-2
U5-9
U6-5
M8-1
U6-8
I5-5
miles

A1-1	Albaqualfs plus Argiabolls
A1-2	Albaqualfs plus Hapludalfs
A7-6	Hapludalfs plus Argiudolls
A7-9	Hapludalfs plus Fragiudalfs
I5-5	Haplaquepts plus Psamaquents
I11-1	Ustochrepts plus Haplustalfs
M2-4	Haplaquoils plus Udifluvents
M6-1	Argiudolls
M6-2	Argiudolls plus Albaqualfs
M6-3	Arguidolls plus Argiaquolls
M6-4	Argiudolls plus Argiaquolls and Argiabolls
M7-4	Hapludolls plus Argiudolls
M8-1	Hapludolls plus Argiustolls
U5-3	Hapludults
U5-9	Hapludults plus Hapludalfs
U5-10	Hapludults plus Hapludalfs
U6-4	Paleudults plus Fragiudults
U6-5	Paleudults plus Hapludults
U6-6	Paleudults plus Hapludults and Fragiadults
U6-8	Paleudults plus Paleudalfs

Figure 77. Major orders and suborders of soil in the Western Interior Region (USGS, 1970).

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are seasonally wet and often require drainage; undrained soils support pasture and woodland. The upper soil horizon has a bleached white appearance, grading sharply to clay accumulations in the subsoil.

The dominant soils of this area are the Hapludalfs, which are usually found on the sides of steep valleys. They are usually moist, relatively high in bases, and low in organic matter.

The Argiudolls of northern Missouri occupy gently to moderately sloping areas and were developed from fine textured glacial till or thin loess. The surface soil is rich in organic matter and the subsoil is usually a brown-colored clay. The Hapludalfs (described above) are associated with these soils on the broad upland flats and the valley slopes. The Argiudolls characteristically lack calcium carbonate and gypsum accumulations, hence the subsoils are acid.

The soils of northern Missouri have the highest land capability rankings (classes I-IV). The dominant soil limitations are from erosion by water and wind, and from wetness.

From 50 to 60 percent of these soils are in cropland status, and from 10 to 30 percent are in pastures. Soils located on the steeper slopes remain in woodland. What limited alluvial soils exist on the floodplain are very important locally for agricultural and wildlife uses.

Southwestern Missouri

In this area the Alfisol and Ultisol soil groups dominate. The Alfisols include the Albaqualfs and the Brunizems. These soils characteristically possess a bleached (white) upper horizon. They occur on gently sloping areas in association with black friable surface soils that are rich in organic matter and exchangeable calcium (Brunizems and Soloths). The Brunizems occupy the gently to moderately sloping areas. The Albaqualf subsoils characteristically possess a clay subsoil with a high base content and a poor internal drainage. The best use of these soils is for pasture and woodlands.

The Ultisols (the Paleudults, formerly the Red-Yellow Podzolic soils) lie to the east of the Albaqualfs and occupy most of southwestern Missouri. They occur on moderately sloping areas (between 10 and 25 percent) and characteristically possess a thick (clay) subsoil that is essentially free of weatherable minerals and low in organic matter. The surface soils have a low base saturation, hence may require lime to maintain soil pH and calcium at levels that are optimal for plant growth. Their best uses are for general crops, pasture, woodland, and wildlife.

The soils of southwestern Missouri have the lowest land capability rankings (classes V-VIII). About 33 percent of these soils are suited to cultivation. The dominant soil limitations are erosion by water, shallowness, stoniness, and droughtiness. The alluvial soils on the floodplains are locally important and very productive for such crops as corn and soybeans.

Eastern Kansas, Oklahoma, and Western Arkansas

The dominant soil groups are the Argiudolls (formerly the Brunizems and Reddish Prairie soils). The Argiudolls have a very dark brown to black-colored surface layer that is rich in organic matter and generally low in bases (acid reaction). The clay subsoil varies in color from brown to reddish. These soils are best used for corn, small grains, and pasture.

The Red-Yellow Podzolic soils occur largely in the Boston Mountains and the Arkansas Valley of western Arkansas. They generally occupy the moderately sloping areas (10-25 percent slopes) such as ridge tops, terraces, and foot slopes. The surface soil is light-colored, and relatively low in organic matter and acid when it is compared to the Brunizem and Prairie soils. Their best uses are for general farms, pasture, woodland, and wildlife.

The soils of this region have low land capability ratings (V-VII). The dominant soil limitations arise from overland erosion, stoniness, and droughtiness. The alluvial soils along the floodplains rank locally as among the best soils for the production of corn, soybeans, and other late season crops.

CONCLUDING REMARKS

Any inventory of soils, surface water, groundwater, coal and related resources requires constant updating as new data becomes available or as the scale of mapping is enlarged. This volume was intended to provide an overview and cannot by its nature be considered adequate for planning individual mines. Site specific data will be needed for each mine within a coal producing region. It should be clear, however, that more soils, geological, and hydrological mapping should be undertaken coal basin by coal basin to facilitate both mine specific planning and more regional planning and development of this nation's coal resources. The necessary data base for either scale of effort is entirely inadequate at present.

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